A PRELIMINARY ANALYSIS
OF THE M140 RECOIL MECHANISM

by

Arthur D. Newsham, Enzo O. Macagno, and Tin-Kan Hung

Conducted as Part of the
Research Study of the Hydrodynamics of
Recoil Systems
Sponsored by
U.S. Army Rock Island Arsenal
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INTRODUCTION

Late in 1965, a report entitled "Analysis of the XM37 Recoil Mechanism" [1] was presented in connection with a study being conducted at the Iowa Institute of Hydraulic Research for the Rock Island Arsenal. In December, 1965, a subsequent report was completed, outlining the effect of the steady discharge coefficient and guide friction on the analysis of the XM37 Recoil Mechanism [2]. In the present report the M140 Recoil Mechanism, including the coil spring, is analyzed in a manner similar to that followed for the XM37 Recoil Mechanism.

In addition to obtaining information on the geometry of the M140 Recoil Mechanism, a pumping test similar to that performed on the XM37 has been completed to evaluate the effective bulk modulus. Since no meaningful analysis of the recoil mechanism can be performed without data obtained by subjecting the mechanism to firing conditions, tests were conducted on one of the powder "gymnasticators" at the Rock Island Arsenal. The pertinent results for a number of rounds have been reduced and analyzed.

In spite of differences in geometry and kinematics, the M140 Recoil Mechanism is quite similar to the XM37 Recoil Mechanism in that the mass of fluid is small relative to the mass of the recoiling parts and the maximum pressure changes occurring during the recoil cycle are of similar magnitude for both mechanisms. The total time required for recoil on the M140 is approximately 50 percent of that on the XM37, while the maximum recoil distance is only 25 percent of that for the XM37. Consequently, it may be expected that the accelerations observed for the M140 will not be significantly different from those found for the XM37. In the light of these similarities, it becomes apparent that the analysis of the fluid system of M140 can be analogous to that for the XM37. There is, however, a major difference between the analytical procedure used for the M140 and


that used for the XM37. This difference stems from the fact that the present analysis can be used directly in the design phase rather than only providing a check on an already completed design. More specifically, the present procedure defines the cross-sectional area of the control-section for a predefined pressure curve rather than predicting the pressure curve for a given control-section cross-sectional area. This line of attack was illustrated in a progress report of 1961 for a simplified model of the recoil mechanism for which the rate-of-flow curve was determined to satisfy a prescribed pressure curve [3]. In addition to being more useful for design, the computational method presented here exhibits considerably more numerical stability than that used heretofore.

ANALYSIS

The M140 Recoil Mechanism, the geometry of which is much simpler than that of the XM37 Recoil Mechanism studied previously [1], could probably be analyzed using the complete one-dimensional compressible-flow equations for the region upstream from the control section [3, 4]. However, the analysis of a simplified system, presented in Appendix A of "Analysis of the XM37 Recoil Mechanism" [1], indicates that the M140 fluid system can be studied using the simplified compressible-flow equations in which the momentum of the fluid column is neglected and the pressure waves do not appear [5]. A simplified set of equations can be used to analyze the M140 Recoil Mechanism because the fluid column is relatively short making the time required for a pressure wave to traverse the fluid region upstream from the control section short compared to the duration of the applied force.

One troublesome feature of the M140 - which should be avoided in future designs - is the complicated control section which will allow the control point to shift during recoil and for a period will produce a dual control, with a significant intermediate pressure. In addition, a new element, the coil spring, which in combination with the fluid system acts to retard the motion, must be investigated carefully to determine if the complete dynamic equations of a coil spring need be utilized or if the usual linear relationship between displacement and force can be assumed without causing significant errors in the analysis. For this initial study, the simplified linear relationship for the spring will be used.

Initial Simplifications. A sketch of the M140 Recoil Mechanism is shown in Fig. 1. To facilitate the analysis, several reasonable simplifying assumptions were made. The simplified system, shown in Fig. 2, was obtained by reducing the control section to three orifices at the primary control points and assuming that there is no interaction between


the fluid and the spring.

Due to the motion causing a portion of the recoiling parts to leave the region, it may be seen in Fig. 2 that the total volume occupied by the fluid increases during recoil. Since the initial oil pressure throughout the entire system is atmospheric and the upstream oil pressure, $P_1$, is well above atmospheric during recoil, the downstream pressure, $P_3$, must be below atmospheric if the entire system is sealed from the surroundings. Obviously, the oil in the downstream region will vaporize, thereby guaranteeing that no pressure below the vapor pressure of the oil will exist there. On the other hand, if the seal breaks down permitting air to enter the downstream region, the pressure downstream from the control may be as high as atmospheric. The effect of these two possibilities will be investigated later in this study.

Equations Governing the System. The motion of the recoiling parts of the mechanism shown in Fig. 2 can be determined by writing the momentum equation, in the direction of motion between sections A and C indicated in Figs. 3 and 4. This equation can be written for a coordinate system fixed to the ground, or for a system attached to the recoiling parts. The latter was employed for convenience leaving the expression for the local acceleration in an unspecified form. For a recoil distance, $x(t)$, less than 2.75 inches, the control sections 2 and 3 are effective as well as the control section 1, and as a result Fig. 3A is applicable. When $x(t) > 2.75$ inches (Fig. 4A) no flow constriction exists at control section 3 and, as a result, control section 2 is also no longer effective. Relating the sum of the forces in the x-direction to the resulting change in momentum gives

$$- \int_{V_f} \rho \frac{\partial V}{\partial t} \, dV_f + EF = \int_c \rho V^2 dS - \int_A \rho V^2 dS \quad (1)$$

In this equation, $\rho$ is the mass density of the hydraulic fluid, $V$ is the velocity at a prescribed point within the fluid region contained between the two sections A and C, $V_f$ is the volume of fluid contained between the two same sections, and $EF$ is the summation of the external
forces acting in the x-direction upon the fluid region under consideration. The term

\[ \int_{\Psi_f} \rho \frac{\partial \Psi}{\partial t} \, d\Psi_f \]  \hspace{1cm} (2)

is included to account for the force introduced by the mass acceleration of the fluid.

Due to the volume of fluid contained between sections A and C being small, compressibility effects may be neglected because they will be small relative to the discharge into or out of the control volume being considered. If \( Q_1 \) is defined as the discharge through control section 1, incompressible flow gives

\[ Q_A = Q_C = Q_1 \quad \text{and} \quad \rho_A = \rho_C = \rho \]  \hspace{1cm} (3)

when conservation of mass is considered.

From Fig. 3A it may be seen that \( \Sigma F \) will be:

\[ \Sigma F = P_1 A_1 - P_3 A_3 - F_r - F_c \]  \hspace{1cm} (4)

in which \( F_r \) is the total force exerted by the recoiling parts on the fluid, \( F_c \) is the force exerted on the fluid by the edge of the interior side of the cylinder at control 3, and \( P_1 \) and \( P_3 \) are the fluid pressures at the respective sections A and C. \( A_1 \) and \( A \) are the cross-sectional areas of sections A and C, respectively. Over the section A the velocity distribution may be assumed uniform. Therefore it may be seen that

\[ V_A = \dot{x}(t) \]  \hspace{1cm} (5)

in which \( \dot{x}(t) \) is the instantaneous velocity of the recoiling parts.

Due to the proximity of section B to the control sections 2 and 3, the velocity distribution across section B cannot be assumed uniform. Instead, a velocity distribution of the form given in Fig. 3C will be assumed.
Both jets will have the same velocity because the same pressure drop occurs across control sections 2 and 3. This gives

\[
\int_C \rho v^2 dS = \rho [Q_2 v_{J2} + Q_3 v_{J3}] = \rho (Q_2 + Q_3) v_{J2}
\]  

(6)

where \( Q_2 \) and \( Q_3 \) are the discharges past the control sections 2 and 3 respectively, and \( v_{J2} \) is the velocity of the fluid jets produced downstream from the respective control sections. The assumption of incompressible flow within the control sections demands that

\[
Q_1 = Q_2 + Q_3
\]  

(7)

Introducing Eqs. (4), (5), (6) and (7) into Eq. (1) results in

\[
\rho \int_{V_f} \frac{\partial v}{\partial t} dv + P_1 A_1 - P_3 A_3 - F_r - F_c = \rho Q_1 [v_{J2} - \dot{x}(t)]
\]  

(8)

A similar application of the momentum between sections B and C in Fig. 3B gives

\[
P_2 A_2 - P_3 A_2 - F_c = \rho [Q_3 v_{J2} - Q_1 v_{J1}]
\]  

(9)

where \( P_2 \) is the pressure in the region between control section 1 and control sections 2 and 3, \( A_2 \) is the area of section B indicated in Fig. 3B, and \( v_{J1} \) is the velocity of the jet issuing from control section 1.

Applying the equation for accelerated motion to the recoiling parts gives

\[
F - S_m - F_r - F_c = \frac{W}{g} \ddot{x}(t)
\]  

(10)

in which \( F \) is the force applied to the recoiling parts by the breech, \( S_m \) is the force exerted by the coil spring, \( F_r \) is the friction force due to the recoiling parts sliding in the guides, \( W \) is the weight of the recoiling parts, \( g \) is the acceleration due to gravity, and \( \ddot{x}(t) \) is the
acceleration of the recoiling parts.

Combining Eqs. (9) and (10) with Eq. (8) to eliminate $F_r$ and $F_c$, one has

$$\rho \int_t \frac{3V}{\partial t} \frac{dV_f}{t} + P_1 A_1 - P_3 A_3 + \frac{W}{g} \tilde{x}(t) + S_m + F_g - F + P_2 A_2$$

$$- P_2 A_2 + \rho[Q_3 V_{j2} - Q_1 V_{j1}] = \rho Q_1[V_{j2} - \dot{x}(t)]$$

(11)

After rearranging terms Eq. (11) simplifies to

$$\frac{W}{g} \tilde{x}(t) + \rho \int_t \frac{3V}{\partial t} \frac{dV_f}{t} = F - P_1 A_1 + P_2 A_2 + P_3(A_3 - A_2) - S_m$$

$$- F_g + \rho[Q_1(V_{j1} - \dot{x}(t)) + Q_2 V_{j2}]$$

(12)

Since the fluid mass between sections A and C will be much smaller than the mass of the recoiling parts and the mean acceleration of the fluid will be of the same order of magnitude as the acceleration of the recoiling parts, the mass acceleration of the fluid can be neglected, and one obtains

$$\frac{W}{g} \tilde{x}(t) = F - P_1 A_1 + P_2 A_2 + P_3(A_3 - A_2) - S_m - F_g$$

$$+ \rho[Q_1(V_{j1} - \dot{x}(t)) + Q_2 V_{j2}]$$

(13)

This equation applies for $\tilde{x}(t) \leq 2.75$ inches.

When $\tilde{x}(t)$ is greater than 2.75 inches, Fig. 4A is applicable. Again, applying the momentum equation between sections A and C, but considering the velocity distribution at the downstream section to be of the form given in Fig. 4B, one can show that

$$\rho \int_t \frac{3V}{\partial t} \frac{dV_f}{t} + P_1 A_1 - P_3 A_3 - F_r = \rho Q_1[V_{j1} - \dot{x}(t)]$$

(14)

Then by applying Eq. (10) and neglecting the mass acceleration of the fluid for reasons already discussed the equation defining the motion of the
The magnitude of the applied force \( F(t) \) provided by the breech, and the upstream pressure, \( P_1(t) \), were obtained from experiments and will be discussed at length in the following section on "Input and Verification Data". The downstream pressure, \( P_3(t) \), will be taken to be either atmospheric or the vapor pressure of the oil and the effect of this variation will be discussed in the results. In Table 1, the areas, \( A_1 \), \( A_2 \), and \( A_3 \), the weight of the recoiling parts, \( W \), are given.

Due to the symmetry of the mechanism, no significant lateral forces should be exerted by the guides. Consequently, the magnitude of the sliding friction, \( F_g \), will be defined as

\[
F_g = \mu W \tag{16}
\]

where \( \mu \) is the coefficient of sliding friction and \( W \) is the weight of the recoiling parts. The value of \( \mu \) to be considered, which is identical to that used in the study of the XM37 Recoil Mechanism [2], is indicated in Table 1.

A number of studies [6, 7, 8] to determine the effect of motion on the forces exerted by a coil spring are available in the literature. Initial indications from a computational analysis under way are that the effect of the mass of the spring on the forces exerted by the spring will

not be negligible. However, since none of the methods outlined in the literature can be applied directly, the spring will be assumed to be massless for this initial study. In a second phase, the dynamic treatment of the spring, now under development, will be applied. Although this simplification may have a noticeable effect on the results, significant information on the importance of other factors can still be obtained. For a massless linear spring the following equations can be written:

\[ S_m(t) = S_f(t) \]  \hspace{1cm} (17)

and

\[ S_m(t) = kx(t) + S_m(0) \]  \hspace{1cm} (18)

in which \( S_m \) and \( S_f \) are the forces exerted by the moving and fixed ends of the coil spring respectively, \( k \) is the spring constant given in Table 1, and \( x \) is the distance the moving end of the spring has been displaced from its in-battery position. \( S_m(0) \) is the static internal elastic force in the spring when the mechanism is in battery and its value is also given in Table 1. All remaining variables in Eq. (13) or Eq. (15), \( P_2, Q_2, V_{J1}, \) and \( V_{J2} \), can be determined by considering mass continuity of the fluid, and the discharge equations governing the various constrictions in the control section.

Consider a fixed volume element \( \delta V \) of length \( \delta S \) and cross-sectional area \( A \). An element of this area could be considered instead, but it is easily seen that, because of the one-dimensional approach, the element could be expanded to the area \( A \) without affecting any of the other variables. The total mass of fluid within the volume \( \delta V \) will vary with time, so by equating the net mass flux into the element to the rate of change of the fluid mass within the volume element, the equation of continuity is obtained as

\[ \frac{\partial (pA\delta S)}{\partial t} = - \frac{\partial (pQ)}{\partial S} \delta S \]  \hspace{1cm} (19)
Expanding the partial derivatives and dividing both sides by \(A\delta S\), one can find the following expression:

\[
\frac{\partial p}{\partial t} + \rho \frac{\partial (Q/A)}{\partial S} + \frac{Q}{A} \frac{\partial p}{\partial S} = 0
\]  

(20)

Liquids used in recoil mechanism, as all liquids, are compressible. It is customary to indicate the compressibility of liquids by means of the bulk modulus of elasticity as defined by

\[
\frac{1}{B} = -\frac{1}{\rho} \frac{\partial \rho}{\partial P}
\]

(21)

From Eq. (21) and \(\partial \rho = \text{const}\), the following equation of state follows almost immediately

\[
\frac{\partial P}{\partial \rho} = \frac{B}{\rho}
\]

(22)

It is assumed that during a single recoil operation there is not enough variation in temperature to justify the use of a more complete equation of state. The bulk modulus of elasticity depends also on the pressure prevalent in the liquid, but it will be assumed to be constant in the following calculations. Since the density is only a function of the pressure \(P\), the partial derivatives of \(\rho\) with respect to \(S\) and \(t\), may be written in the form:

\[
\frac{\partial \rho}{\partial S} = \frac{\partial \rho}{\partial P} \frac{\partial P}{\partial S} = \frac{\rho \partial P}{B \partial S}
\]

(23)

\[
\frac{\partial \rho}{\partial t} = \frac{\partial \rho}{\partial P} \frac{\partial P}{\partial t} = \frac{\rho \partial P}{B \partial t}
\]

(24)

From the equation of state and continuity, the following equation can now be obtained

\[
\frac{\partial P}{\partial t} + B \frac{\partial (Q/A)}{\partial S} + V \frac{\partial P}{\partial S} = 0
\]

(25)
As the effects of pressure waves have been shown to be negligible for similar systems [1] and the complete one-dimensional compressible-flow equation will not be considered, variations in pressure with position will be neglected. Consequently, \( \frac{\partial P}{\partial S} = 0 \) and Eq. (26) can be simplified to

\[
\frac{dP}{dt} = - B \frac{d(Q/A)}{ds} \tag{26}
\]

At any time \( t \), this equation can be integrated with respect to \( s \); as neither \( P \) nor \( B \) are functions of \( S \), the result is simply given by

\[
- \frac{A}{B} \frac{dP}{dt} \int_0^{L-x(t)} ds = \int_{q_{in}}^{q_{out}} dq
\]

\[
- \frac{\psi}{B} \frac{dP}{dt} = q_{out} - q_{in} \tag{27}
\]

where \( q_{in} \) and \( q_{out} \) are the volume rate of discharge into and out of the region, respectively, and \( \psi \) is the volume defined as

\[
\psi = A_0 [L - x(t)] \tag{28}
\]

Applying Eq. (27) to the region upstream from the control section, one obtains

\[
A_0 \dot{x}(t) = Q_1(t) + \frac{\psi}{B} \frac{dP}{dt} \tag{29}
\]

in which \( A_0 \) is the cross-sectional area of the annular region upstream from the control section, \( Q_1 \) is the discharge through the first constriction in the control section, and \( L \) is the in-battery length of the annular region upstream from the control section.

Within the control section the fluid has been considered incompressible. The error introduced by assuming no storage in this region is negligible because the compressibility term is small compared to the
discharge into or out of the region. Since the efflux velocity from control sections 2 and 3 must be identical and Eq. (7) must be satisfied,

\[ Q_2 = \frac{Q_2}{Q_2 + Q_3} \]

\[ Q_2 = \frac{C_{D_2}A_{O_2}}{C_{D_2}A_{O_2} + C_{D_3}A_{O_3}} \]  

(30)

The standard equation for the orifice discharge \( Q(t) \) is

\[ Q(t) = C_{D(t)}A_{O(t)}\sqrt{\frac{2\Delta P(t)}{\rho}} \]  

(31)

in which \( C_{D(t)} \) is the discharge coefficient for the instantaneous conditions, \( A_{O(t)} \) is the minimum cross-sectional area of the constriction, and \( \Delta P(t) \) is the pressure drop across the constriction. When Eq. (31) is substituted into Eqs. (29) and (7) for the various discharges, the equation

\[ A_0 \dot{x}(t) = C_{D_1}A_{O_1}\sqrt{\frac{2}{\rho}(P_1 - P_2)} + \frac{\psi}{B} \frac{dP_1}{dt} \]  

(32)

and the expression

\[ C_{D_1}A_{O_1}\sqrt{\frac{2}{\rho}(P_1 - P_2)} = \left[ C_{D_2}A_{O_2} + C_{D_3}A_{O_3}\right] \sqrt{\frac{2}{\rho}(P_2 - P_3)} \]  

(33)

are obtained. If both sides of Eq. (33) are squared it can be rearranged to give

\[ P_2 = P_1 \left\{ 1 + \left( \frac{C_{D_2}A_{O_2} + C_{D_3}A_{O_3}}{C_{D_1}A_{O_1}} \right)^2 \frac{P_3}{P_1} \right\} \]

\[ 1 + \left( \frac{C_{D_2}A_{O_2} + C_{D_3}A_{O_3}}{C_{D_1}A_{O_1}} \right)^2 \]  

(34)

When \( x(t) \) becomes greater than 2.75 inches the constrictions offered by control sections 2 and 3 no longer exist so that
\[
\frac{CD_{2}AO_{2} + CD_{3}AO_{3}}{CD_{1}AO_{1}} \to \infty
\]

and consequently Eq. (34) reduces to

\[
P_{2} = P_{3}
\] (35)

Therefore Eq. (34) is applicable when \( x(t) \leq 2.75 \) inches and Eq. (35) is applicable when \( x(t) > 2.75 \) inches. Also, Eq. (32) can be written in the form

\[
AO_{1} = \frac{A_{0} [x(t) - \frac{L - x(t) \frac{dP_{1}}{dt}}{B}]}{\sqrt{\frac{2}{\rho} [P_{1} - P_{2}]}}
\] (36)

by introducing Eq. (28) and rearranging terms.

The velocity of the fluid issuing from each of the control sections can be computed quite simply if it is assumed that there is no energy loss between a point a short distance upstream from the control and a point in the jet immediately below the control. Pressure variations due to the acceleration of the fluid will be neglected as they will be small compared to the total pressure drop across a control. The Bernoulli equation in terms of the velocity and pressure at two points \( A \) and \( B \) may be written as:

\[
P_{A} + \rho \frac{V_{A}^{2}}{2} = P_{B} + \rho \frac{V_{B}^{2}}{2}
\] (37)

Applying Eq. (37) across control section 1 and then across control section 2, one has

\[
P_{1} + \rho \frac{V_{1}^{2}}{2} = P_{2} + \rho \frac{V_{2}^{2}}{2}
\] (38)
and

\[ P_2 + \rho \frac{V_2^2}{2} = P_3 + \rho \frac{V_J^2}{2} \quad (39) \]

herein \( V_1 \) and \( V_2 \) are respectively the approach velocities upstream from control sections 1 and 2. Since both \( V_1 \) and \( V_2 \) are small compared to the corresponding jet velocity, their squared values appearing in Eqs. (38) and (39) will be neglected, thus yielding the following equations:

\[ V_{J1} = \left[ \frac{2}{\rho} (P_1 - P_2) \right]^{1/2} \quad (40) \]

and

\[ V_{J2} = \left[ \frac{2}{\rho} (P_2 - P_3) \right]^{1/2} \quad (41) \]

Utilizing Eqs. (16), (18), (28), (29), (30), (35), (40) and (41), Eqs. (13) and (15) can be rewritten in the form:

\[
\frac{\dot{W}}{g} x(t) = F - P_1 A_1 + P_2 A_2 + P_3 (A_3 - A_2) - kx(t) - S_m(0) - \mu W \\
+ \rho A_0 \left\{ \dot{x}(t) - \frac{L - x(t)}{B} \frac{dP_1}{dt} \right\} \left[ \left( \frac{2}{\rho} (P_1 - P_2) \right)^{1/2} - \dot{x}(t) \right] \\
+ \left\{ \frac{CD_2 A_0}{CD_2 A_2 + CD_3 A_3} \right\} \left[ \frac{2}{\rho} (P_2 - P_3) \right]^{1/2} \quad (42) \]

which is valid for \( x(t) \leq 2.75 \) inches; and

\[
\frac{\dot{W}}{g} \dot{x}(t) = F - P_1 A_1 + P_3 A_3 - kx(t) - S_m(0) - \mu W \\
+ \rho A_0 \left\{ \dot{x}(t) - \frac{L - x(t)}{B} \frac{dP_1}{dt} \right\} \left\{ \left( \frac{2}{\rho} (P_1 - P_3) \right)^{1/2} - \dot{x}(t) \right\} \quad (43) \]

which applies for \( x(t) > 2.75 \) inches.
For design purposes, the control-section geometry, or at least some part of it, is generally regarded as an unknown. In the case of the M140 Recoil Mechanism, it appears that the most significant variable in the control section is the area of the first constriction, $A_0$. If $CD_1$, $CD_2$, $CD_3$, $A_0$, and $A_0$ are known, then Eq. (36) in conjunction with Eq. (42) and (34) or Eq. (43), depending upon the value of $x(t)$, can be solved by numerical iteration. In this manner, the motion of the mechanism, $x(t)$, $\dot{x}(t)$, and $\ddot{x}(t)$, and the area of the constriction $A_0$ can be determined. All other variables defined by the various equations can then be determined by direct computation.
INPUT AND VERIFICATION DATA

Considerable information is necessary to define the recoiling system and to evaluate the accuracy of the results of its analysis. The data can be divided into two categories. The first, which will be designated input data, includes all information necessary to define the independent variables in the equations. In a study of this type, additional information is necessary to evaluate the accuracy with which the equations predict the dependent variable; this additional information will be referred to as verification data. Whether a specific variable is a dependent variable, rather than an independent variable, depends upon the term that is regarded as the unknown in the equation. For example, for the present problem pressure can be considered the unknown variable and determined in terms of the control-section area. Conversely, the pressure can be considered as a known variable and the same equations solved for the area of the control section. In any case, there will be only one dependent variable for the entire system. Once the equations have been solved for the dependent variable, it is a simple matter to evaluate additional variables that may be of interest. There can be innumerable checks on the system. Some experimental verification data, such as orifice area, can be used for an instantaneous check on the analysis, whereas data on total recoil provide an integrated check on the analysis from the initiation of recoil. Generally, both types of verification data are desirable.

Prototype tests to evaluate the recoil of the M140 Recoil Mechanism were conducted on a powder gymnasticator at the Rock Island Arsenal on April 16, 1965. The powder gymnasticator is very useful as a design tool because it permits much better control of the experiments than field tests even if these are conducted under the most ideal conditions. For the analysis of a recoil system, it is very important that the experimental data be accurate. Of considerably less relative significance is the requirement that the evaluation be conducted under conditions that reproduce exactly what might occur under normal or extreme
no question that the experimental data obtained using the powder gymnasticator are superior to those obtained from field tests, and, in addition, the powder gymnasticator appears to approximate field conditions very closely. Once the results of the analysis agree with the powder-gymnasticator data, it should be a relatively simple step to apply the field conditions to the analysis and predict the actual operation of the recoil mechanism. From the results of tests conducted on April 16, 1965, data on the applied force, upstream pressure, and recoil distance have been obtained for several rounds.

Both the input data and the verification data must be evaluated carefully. In the case of recoil mechanisms in which the experiment is completed in a fraction of a second, many difficulties - which have an effect on the accuracy of the results - are encountered when obtaining the data. For this reason, it is desirable to repeat an experiment a number of times and then compare the data for inconsistencies. Care must be exercised that errors in the experimental data are not interpreted as errors in the mathematical model.

Geometry. Although the geometry has been simplified considerably for the analysis (Fig. 2), the dimensions controlling the dynamics of the mechanism have been retained or have been changed in such a manner that the motion during recoil will not be affected. In Table 1, the annular area, \( A_0 \), is the average area of the fluid region upstream from the control section and the length, \( L \), is the length of the upstream fluid region when the mechanism is in battery. The annular areas, \( A_1 \), \( A_2 \), and \( A_3 \), have been defined as the areas over which the respective pressures, \( P_1 \), \( P_2 \), and \( P_3 \), are effective (see Fig. 2). The orifices have been simplified in Fig. 2 but their discharge coefficients \( C_{D_2} \) and \( C_{D_3} \), and their cross-sectional areas, \( A_{O_1} \), \( A_{O_2} \), and \( A_{O_3} \), are defined to reproduce the constrictive effects of the actual control section during the entire recoil phase.

In the analysis, the orifice area, \( A_{O_1} \), is regarded as an unknown and therefore any information provided by a knowledge of the geometry is used to verify results.
Fluid properties. In the MIL-Recoll Mechanism, the oil (MIL-0-5606) has a mass density, \( \rho \), of 1.61 lb-sec\(^2\)/ft\(^4\). The adiabatic bulk modulus of elasticity of the oil has been determined in a laboratory over the full range of temperatures and pressures at which the system is designed to operate. Rather than laboratory values of the adiabatic bulk modulus, one should use as the measure of the compressibility the relationship between an incremental pressure rise, \( \Delta P \), in a closed volume \( V \) of fluid in the recoil mechanism and the addition of an incremental volume of fluid, \( \Delta V \), according to the following relationship:

\[
\Delta P = B \frac{\Delta V}{V}
\]

(45)

If the container were perfectly rigid, this would give a value of \( B \) identical to the bulk modulus of the oil. However, the recoil mechanism is not perfectly rigid, and due to the complicated geometry an accurate calculation of the dilatation of the cylinders with pressure is not possible. The effective bulk modulus of the MIL-Recoll Mechanism could only be determined experimentally by a pumping test.

Pumping tests were conducted on an MIL-Recoll Mechanism at the Rock Island Arsenal in August, 1965. The results are presented in Table 2 and Fig. 5. For comparison, the adiabatic bulk modulus of the oil, MIL-0-5606, is included in Table 2. It can be seen that the effective bulk modulus indicated by the pumping tests is significantly lower than the adiabatic bulk modulus of the fluid. Although there is considerable scatter in the data, it can be seen that the magnitude of the effective bulk modulus tends to exhibit significant oscillations (broken line in Fig. 5) as the pressure on the fluid is increased. The oscillations are probably due to the system expanding suddenly, then being relatively rigid for a considerable pressure increase and then expanding suddenly again rather than expanding elastically at uniform rate as the pressure is increased.

The kinematic viscosity of the oil, \( \nu \), is approximately \( 4 \times 10^{-4} \) ft\(^2\)/sec at 70°F. The effects of viscosity are neglected in the
present analysis because they are assumed to be rather small. They may, however, have a non-negligible influence and should be investigated for a more refined analysis.

Spring Properties. From Eq. (18) it can be seen that the retarding force provided by the coil spring can be determined in terms of the displacement when the spring constant, \( k \), and the internal elastic force present when the system is in-battery, \( S_M(0) \), are known if the mass of the spring is neglected. The values of \( k \) and \( S_M(0) \) were determined from static tests and are given in Table 1.

Sliding Friction. Since the M140 Recoil Mechanism is axisymmetric and all dynamic forces are applied symmetrically about its axis, the normal force on the rails will not be affected by the magnitude of the various forces acting at any instant as in the case of the XM37 Recoil Mechanism [1]. Consequently, the normal force on the rails will be assumed to be equal to the weight \( W \) of the recoiling parts. The rail friction, \( F_g \), will be the normal force on the rails times a coefficient of sliding friction, \( \mu \), (Eq. 16)). Based on tests [9] the value of \( \mu \) has been estimated to be one-third the static value which, for hard steel, is 0.42. Since the value of \( \mu \) is dependent upon many effects not included in this study, a number of different values will be used, and their effect upon the results will be discussed. In order to investigate the influence of \( \mu \) on the displacement, several values of \( \mu \) ranging from 0 to 0.42 were used.

Applied Force. The applied force is determined by multiplying the muzzle area by the data obtained from a Hat-gage pressure cell placed in the muzzle. Since all prototype tests were conducted using a powder gymnasticator, there is no separate method to determine the total applied impulse as is possible by computing the momentum of the projectile and ejected gases in a field test. Therefore the magnitude of the applied force, as given by the Hat-gage, was used without correction. The location of the Hat-gage and application of the force in the gymnasticator test is at the muzzle rather

than at the breech. A force applied to the muzzle end of the gun tube will require a short period of time to be transmitted as an elastic wave along the gun tube to the breech. The time delay has been defined as \( \tau \) so that

\[
F_a(t) = F_e(t - \tau)
\]

where \( F_a \) is the force applied to the recoil mechanism and \( F_e \) is the experimental value of the applied force given by the Hatt-gage. The values of \( F_e \) for a number of rounds are presented in Table 3. An estimate of the time delay can be determined if the elastic modulus, \( E \), the mass density, \( \sigma \), and the length, \( L_g \), of the gun tube are known, since:

\[
\tau = L_g \sqrt{\frac{\sigma}{E}}
\]

**Upstream Pressure.** The pressure upstream from the control section was monitored during the experiments performed on the powder gymnasticator and the values are tabulated in Table 4. The pressure cell was located at approximately the midpoint of the upstream region when the gun was in battery. The location is not important because the pressure variation throughout the entire region upstream from the control section is of the same order of magnitude as the errors inherent in experimentally determining the pressure.

**Displacement.** For the experiments on the powder gymnasticator, the distance the mechanism has recoiled from its in-battery position was determined, and is presented in Table 5 with the results for the applied force and the upstream-pressure curve. Since the recoil distance is not required to solve Eqs. (1) or (2), it provides a check on the analysis.

**Orifice Area.** Similar to the data for displacement, the data for orifice area are not necessary for the solution of Eqs. (1) or (2) and can be used as a verification of the analysis. From the geometry of the mechanism, the orifice area can be expressed as:

\[
A_{01}(t) = 14.4 \pi [0.176 - 0.0132 \times(t)]
\]
Reliability of Data. A close inspection of Tables 3, 4, and 5 indicates considerable variation in the data from one round to another. It may be seen that the time required to reach the maximum applied force may vary by as much as 20 percent. When compared to the average values of all seven rounds tabulated, the integrated results for each round are consistent within themselves. For example, Round 32 has the highest total applied impulse, the highest integrated value of the upstream pressure, and the greatest maximum-recoil distance. From this, it may be concluded that, although the data are not repeatable for successive rounds, they do appear to be consistent among themselves within each round. It also appears from a comparison of the mean value data tests with each original run that the average values would not be representative because of their lacking internal consistency. It seems then preferable to select the round 26 which possesses the integrated characteristics that agrees best with the results of averaging integrated characteristics of all tests. The round 26 with a certain prescribed value of \( u, k, B \), etc., as shown in Table 6 is designated hereafter as the standard run.
DISCUSSION OF RESULTS

For the standard run, as defined in the previous chapter, the relative influence of the various forces acting on the recoiling parts has been investigated by means of a momentum-impulse balance, which in addition serves to check the computationally determined net momentum. This quantity was obtained after solving Eqs. (4.2) and (4.3) for the acceleration \( \ddot{x}(t) \), the velocity \( \dot{x}(t) \) and the displacement \( x(t) \) with the input data; the computational technique is described in detail in Appendix A. Due to the quite different relative magnitudes of the various impulses, these quantities, which are all referred to the total applied-force impulse, are presented using different scales in Figs. 6 and 7. The forces for which the impulses were calculated are the following: the applied force, the upstream and downstream pressure forces, the dynamic force due to internal fluid jets, the coil-spring force, and the friction force. It should be noticed that some of the terms in Figs. 6 and 7 carry a negative sign. The algebraic sum of the impulses deviates little from the values given by the net momentum curve, the maximum deviation being 0.0005 with reference to the total applied-force impulse. It is obvious from Figs. 6 and 7 that the applied force and the upstream-pressure forces have predominant influence on the recoil dynamics; the other forces have a comparatively small effect.

With the aforementioned input data (see Table 6) the displacement of the recoiling parts and the orifice area at control 1\((A_{01})\) have been computed for comparison with the corresponding measured quantities. In Fig. 8, the calculated and the experimentally determined displacements are given for the standard run. The relative difference is defined as \( \frac{(x - x_E)}{(x_E)_{\text{max}}} \). Herein, \( x \) and \( x_E \) are respectively the computed and the measured displacement. The error varies between zero and ten percent; with a value of seven percent at the end of the recoil. Figure 9 is based on an assumption made necessary by the fact that more than one control section exists in this mechanism. Because orifices 2 and 3 present sharp edges it has been considered appropriate to use \( C_D = 0.611 \) for them. The coefficient for orifice 1 is not prescribed; its value can be
calculated if the area \( A_{01} \) is known for the computed values of \( C_{D1}A_{01} \) (Appendix A). On the other hand, if a reasonably good estimate could be made for \( C_{D1} \), the present calculation could be used to determine the orifice area as part of design operations. For the present work a mean value of \( C_{D1} \) has been determined by means of

\[
C_{D1} = \frac{\sum A_{01}C_{D1}}{\sum A_{01E}}
\]

using the values of the product \( A_{01}C_{D1} \), and the values of \( A_{01E} \), determined from the known geometry of the M140 mechanism and the computed displacement. With this average \( C_{D1} \), values of \( A_{01} \) were calculated and are given in Fig. 9. The relative error \( (A_{01} - A_{01E})/(A_{01E})_{\text{max}} \), shows that the effects of unsteadiness on \( C_{D1} \) cannot be neglected for design purposes. This can also be seen from Fig. 10, in which the instantaneous discharge coefficient, obtained from the known value of \( A_{01E} \) and the product \( A_{01}C_{D1} \), is given. According to the present analysis, such a determination of \( C_{D1} \) is not satisfactory. This is probably due to several reasons; the one-dimensional approach, the neglect of viscous effects in the flow development, and the inaccuracies of the input data being the three that are considered as the most important.

A comparison of deviations in the displacement for different rounds is given in Fig. 11. The corresponding calculations were performed with the same values of the different parameters such as spring constant, downstream pressure, rail-friction coefficient, bulk modulus of elasticity, etc. (see Table 6). This figure shows that there is a general trend in the shape of the error curves, but that quantitatively it is still difficult to obtain information from the experiments without important deviations.

To investigate the influence of variations of the input data a series of calculations was carried out in which one parameter at a time was varied while all the others were kept constant. The function subject to this variation of parameters was the displacement. Figure 12 shows the effect of varying the calibration factor for the applied force; a variation of 2 percent has quite important effects. It is obvious that the force
must be determined with a high accuracy in the experiments. The data on applied forces were digitalized by direct measurement on the experimentally recorded curves. This introduced a source of error which is believed to have raised the inaccuracy above one percent. In fact, it is necessary, for a refined analysis, to obtain data with errors well below one percent. Because the upstream pressure has a magnitude of the order of that of the applied force, the influence of its calibration factor is also expected to be important. One should bear in mind that the displacement results from a double integration of the applied forces with respect to the time variable. For example, the error curves shown in Fig. 12 do not differ significantly from one another for small values of time but, as the effect of the integration accumulates, they depart more and more. In comparison to other factors, the applied force has a predominant effect on this type of error.

Another effect that must be taken into account is the time delay in the actual application of the force due to the propagation of the applied impulse from the muzzle to the breech. This time has been estimated to be 0.6 millisecond, and is approximately equal to the value of one time interval ($\delta t = 0.794$ millisecond) used in these computations. In order to be able to appreciate the effect of variations of this parameter, values of $\tau$ equal to $\delta t$, $2\delta t$, and $3\delta t$ were selected. The results obtained are given in Fig. 13 and they show that the exact location of the application of the force in time is important.

In a similar manner, the variations of other parameters have been determined and represented graphically. The influence of variations of the values of the downstream pressure, the rail-friction coefficient, the spring constant, the bulk modulus of elasticity of the oil and the internal jet-reactions are shown in the Figs. 14 to 18. It should be noticed that the parameters $\mu$, $k$, and $B$, for which very large variations were considered, have less influence compared with the other parameters.

Comparison of the error curves shows immediately that, generally speaking, they present an approximate similarity of shape. They have the common feature that variations of these parameters seem to have little effect on the errors during an initial period of about thirty milliseconds; from there on, the curves tend to diverge more strongly for all the parameters studied.
CONCLUSIONS

The present analysis has shown that the one-dimensional approach with a massless spring constitutes an acceptable first approximation for the study of the M140 recoil mechanism. This analysis has proved to be very useful in determining the relative importance of the different variables involved. According to the computational results, it is clear that the effects of deviations in the values of the bulk modulus of elasticity of the hydraulic oil, the spring constant and the rail-friction coefficient are rather small. On the other hand, the time delay, the downstream pressure and the reaction of internal jets have a much larger influence.

For any future experimental verifications utmost care should be exercised in order to improve the accuracy of the recording of the applied force and upstream pressure. It would also be necessary for a more complete verification to measure the downstream pressure.

Acknowledgements

In addition to providing the experimental data necessary for the analysis, Mr. R. H. Coberly of the Rock Island Arsenal arranged for the pumping tests necessary for the determination of the effective bulk modulus. Of the Institute staff, Mr. D. W. McDougall, Research Associate, supervised the pumping tests and critically revised the manuscript, and Messrs. C. Y. Hung and S. T. Hsu, Research Assistants, reduced the experimental results to digital form and completed the drawings.
Table 1. Standardized Geometry of M140 Recoil Mechanism

a. Recoiling Parts and Coil Spring.

\[ W = 2650 \text{ lb} \]
\[ S_m(0) = 3000 \text{ lb} \]
\[ k = 133 \text{ lb/in.} \]
\[ \mu = 0.21 \]

b. Lengths and Annular Areas of Fluid Region.

\[ A_0 = 50.0 \text{ in.}^2 \]
\[ A_1 = 54.0 \text{ in.}^2 \]
\[ A_2 = 24.3 \text{ in.}^2 \]
\[ A_3 = 167.5 \text{ in.}^2 \]
\[ L = 22.5 \text{ in.} \]

c. Control-Section Geometry.

\[ A_{01E} = 7.97 - 0.597x(t) \text{ in.}^2 \]
\[ A_{02} = 8.00 \text{ in.}^2 \]
\[ A_{03} = 0.212 \text{ in.}^2 \text{ for } x(t) < 0.25 \text{ in.} \]
\[ = 0.212 + 1.0179(x(t) - 0.25) \text{ in.}^2 \text{ for } 0.25 \leq x(t) \leq 2.75 \text{ in.} \]
\[ C_{D2} = 0.611 \]
\[ C_{D3} = 0.611 \]

d. Gun Tube.

\[ L_g = 120 \text{ in.} \]
\[ \sigma = 0.284 \text{ lb/in.}^3 \]
\[ E = 30,000,000 \text{ lb/in.}^2 \]
Table 2. Fluid-Elastic Properties of M140 Recoil Mechanism

\[ \rho = 1.61 \text{ slugs/ft}^3 \]
\[ \nu = 4 \times 10^{-4} \text{ ft}^2/\text{sec} \]

Bulk Modulus of Elasticity at 78°F

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Table 3. Force Applied to M140 Recoil Mechanism From Tests Conducted on April 26, 1966

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Total Impulse (lb·sec)  
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Percentage Error Relative to Mean Impulse  
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**Percentage Error Relative to Mean Impulse**

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Table 5 Continued

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<td>11.610</td>
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<td>11.718</td>
<td>11.637</td>
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<tr>
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<td></td>
<td>11.718</td>
<td>11.637</td>
<td>11.583</td>
<td>11.556</td>
<td>11.610</td>
<td>11.718</td>
<td>11.664</td>
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</table>

Percentage Error Relative to Mean Displacement

|               | 0.66 | -0.03 | -0.50 | -0.73 | -0.27 | 0.66 | 0.20 |

Table 6. **Standard-Run Data**

Round No. 26

Force calibration factor = 100%

\[ B = 135,000 \text{ psi} \]

\[ k = 133 \text{ lb/in} \]

\[ \mu = 0.21 \]

\[ P_3 = 0 \]

\[ \tau = 0 \]

Internal jet-momentum impulse included.
Fig. 1. Sketch of the M140 recoil mechanism.
Fig. 2. Definition of control sections, and regions with different pressures for a simplified mechanism
Fig. 3A and 3B. Cross sections and forces used in the calculations.
Fig. 3C. Velocities assumed at different sections for the momentum analysis
Fig. 4A. Geometry assumed for the second phase in the analysis,

\( x(t) > 2.75 \text{ inches} \)
Fig. 4B. Velocities at different sections for the second phase in the analysis, \( x(t) > 2.75 \text{ inches} \)
Fig. 5. Effective bulk modulus by pumping tests on the M140 Recoil Mechanism at the Rock Island Arsenal
Fig. 6. Momentum-Impulse balance in the M140 recoil mechanism, (small terms are given in Fig. 7)
Fig. 7. Impulse of different forces
Fig. 8. Comparison of computed and experimentally determined displacement for the standard run
Fig. 9. Comparison of experimental and computed orifice area

\[ A_0' \text{ ERROR} = \frac{(A_0' - A_0)}{A_0'} \]
Fig. 10. Calculated values of the discharge coefficient
Fig. 11. Comparison of the deviations in the displacement for the different rounds
Fig. 12. Effect of variations of the calibration factor for the applied force
Fig. 13. Influence of time delay of the applied force on the displacement error
Fig. 14. Influence of the value of the downstream pressure on the displacement error.
Fig. 15. Influence of the assumed rail coefficient on the displacement error
Fig. 16. Influence of the spring constant on the displacement error.
Fig. 17. Influence of different values of the bulk modulus of elasticity on the displacement error.

$$\text{DISP ERROR} = \frac{(x-x_0)^3}{x_0^3}$$
Fig. 18. Influence of different assumptions on the reactions of internal jets on the displacement error
Appendix A
COMPUTER PROGRAM

Numerical Technique

In the analysis of the XM37 recoil mechanism [1], computations were conducted to determine acceleration, velocity, displacement and pressure for a prescribed orifice area. For the ML40 recoil mechanism, the computational procedure has been reversed in the sense that the upstream pressure is given and the acceleration, the velocity, the displacement and the orifice area at section 1 are computed. In the present calculations, no numerical instability has been encountered, while for the XM37-recoil-mechanism study, numerical instability arose in the determination of pressure. The improved numerical stability found for this case may be due to using the pressure rather than the orifice area as one of the prescribed variables.

The numerical solution for the computed acceleration, velocity, and displacement is obtained from equation of motion of the recoiling parts (Eqs. 42 and 43); the computations proceed as follows:

1) Read into the computer all necessary data.

2) Assume the acceleration of the recoiling parts and the orifice area at section 1 are equal to the corresponding values at the previous time. Compute the velocity and displacement for the new time by numerical integration using the trapezoidal rule.

3) Calculate the acceleration at the new time with Eq. (42) for \( x(t) \) less than 2.75 inches, or with Eq. (43) if \( x(t) \) is larger than 2.75 inches.

4) Repeat step 3 at least once, check if the computed displacement and orifice area have converged; if not, repeat step 3 using the latest estimate for acceleration and orifice area. If convergence conditions are satisfied, advance one time-increment, and repeat
steps 2 to 4 until the velocity of the recoiling parts becomes negative.

A detailed description of the computer program is given in the flow charts. The program is written in FORTRAN IV for the IBM 7044 Computer at the University of Iowa Computer Center.
### Definition of Terms

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<thead>
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<th>Term</th>
<th>Description</th>
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<td>A</td>
<td>acceleration of the recoiling parts</td>
</tr>
<tr>
<td>A1</td>
<td>area of the normal wall at section 1</td>
</tr>
<tr>
<td>A2</td>
<td>area over which P2 is effective</td>
</tr>
<tr>
<td>A3</td>
<td>area at section CC (Fig. 3a)</td>
</tr>
<tr>
<td>AM</td>
<td>mass of the recoiling parts</td>
</tr>
<tr>
<td>AO</td>
<td>mean cross section area in the upstream region</td>
</tr>
<tr>
<td>AO1</td>
<td>computed orifice area at the control section 1</td>
</tr>
<tr>
<td>AO2</td>
<td>orifice area of control section 2</td>
</tr>
<tr>
<td>AO3</td>
<td>computed orifice area at 3</td>
</tr>
<tr>
<td>AO1ER</td>
<td>error of control section 1 orifice area</td>
</tr>
<tr>
<td>AO1EX</td>
<td>measured orifice area at the control section 1</td>
</tr>
<tr>
<td>AO1ST</td>
<td>in-battery orifice area</td>
</tr>
<tr>
<td>B</td>
<td>bulk modulus of elasticity of oil</td>
</tr>
<tr>
<td>CALF</td>
<td>calibration factor for applied force</td>
</tr>
<tr>
<td>CALPL</td>
<td>calibration factor for upstream pressure</td>
</tr>
<tr>
<td>CAIXE</td>
<td>calibration factor for experimental displacement</td>
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<td>CD2, CD3</td>
<td>steady discharge coefficient</td>
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<tr>
<td>CF</td>
<td>coefficient of rail friction</td>
</tr>
<tr>
<td>DELT</td>
<td>time interval between computations</td>
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<td>DIFF</td>
<td>displacement error</td>
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<td>applied force</td>
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<td>jet momentum at section 1</td>
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<td>spring force in battery</td>
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<td>FS</td>
<td>spring force</td>
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<tr>
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<tr>
<td>Symbol</td>
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<td>pressure at section 2</td>
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<td>downstream pressure</td>
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<tr>
<td>Q3</td>
<td>discharge past section 3</td>
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<td>equivalent discharge due to the motion of recoiling part</td>
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<td>density of oil</td>
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<td>applied-force impulse</td>
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<td>SUMFJ</td>
<td>sum of jet momentum 1 and 2</td>
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<tr>
<td>SUMFR</td>
<td>sliding-friction impulse</td>
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<td>SUMFS</td>
<td>spring-force impulse</td>
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<td>SUMP1</td>
<td>upstream-pressure impulse</td>
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<td>sum of pressure forces at sections 2 and 3</td>
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<td>time</td>
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<td>total impulse</td>
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<td>velocity of the recoiling parts</td>
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<td>computed displacement of the recoiling parts</td>
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<td>momentum of recoiling parts</td>
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Flow Chart

START

READ-MAXDEL, NRUN

DO 15 KJI = 1,NRUN

READ-JREA1, JREA2

READ-CF, XKS, FO, W, B, RHO, A01ST, A02
A0, A1, A2, A3, X11, P3, CD2, CD3

READ-CALF, CALPL, CALXE, DELT, ERR, NMAX, NEND

READ-NF, NR, (F(I), I = 2,NF)

READ-NX,(XE(I),I=2,NX)

READ-NP,(P(I),I=2,NP)

READ NUMBER OF TIME DELAYS AND NUMBER OF RUNS

READ LOGICAL CONTROL OF FLUID MOMENTUM

READ CONSTANTs

READ APPLIED-FORCE DATA

READ MEASURED-DISPLACEMENT DATA

READ UPSTREAM-PRESSURE DATA
DEFINE CONSTANTS

EXTEND UPSTREAM-PRESSURE DATA

EXTEND DISPLACEMENT DATA

EXTEND APPLIED-FORCE DATA

DIMENSIONAL STATEMENT INSUFFICIENT
\begin{verbatim}
X(1) = 0.0
XE(1) = 0.0
DIFF(1) = 0.0
V(1) = 0.0
A(1) = 0.0
AO3(1) = 0.0
QO(1) = V(1)*AO
QL(1) = AO*V(1)
Q2(1) = QL(1)
Q3(1) = 0.0

T(1) = 0.0
P1(1) = 0.0
P2(1) = 0.0
FJ1(1) = 0.0
FJ2(1) = 0.0

FS(1) = FO
F(1) = 0.0
SUMP(1) = 0.0
SUMP1(1) = 0.0
SUMP2(1) = 0.0
SUMP25(1) = 0.0
SUMP25(1) = 0.0
SUMFS(1) = 0.0
SUMFR(1) = CF*W*T(1)
XOM(1) = AM*V(1)
TOTIMP(1) = SUMP(1) - SUMP1(1) - SUMFS(1)

JREAC1

TRUE

FJ1(1) = RHO*QL(1)*SQRT(2.0*(P1(1) - P2(1))/RHO) - V(1))

FALSE

JREAC2

TRUE

FJ2(1) = RHO*Q2(1)*SQRT(2.0*(P2(1) - P3)/RHO)

FALSE

1-3
\end{verbatim}
1-3

DO 2 I=1,NEND

NT(I)=0
T(I)=DELT*FLOAT(I-1)
P(I)=F(I)*CALF
PL(I)=PL(I)*CALPL
XE(I)=XE(I)*CALXE

2

MODELL = MAXDEL + 1

DO 15 IJK = 1,MODELL

A0LX(I) = A0LST
A0L(I) = A0LX(I)
CDL = 0.0
CDLEX = 0.0
NDEL = IJK - 1

DO 1 I=2,NEND

NPLT = I
TEMP1 = P(I) + PG3

A(I) = A(I-1)
A0L(I) = A0L(I-1)

50

NT(I) = NT(I) + 1
V(I) = (A(I)+A(I-1))*DELT2+V(I-1)
X(I) = (V(I)+V(I-1))*DELT2+X(I-1)
FS(I) = FO + XKS*X(I)

X(I) < 0.0 and TEMP1 < 0.0

TRUE

FALSE

1-4

COMPUTE TIME, FORCE
PRESSURE AND DISPLACEMENT
FOR A COMPLETE RUN

PERFORM ADDITIONAL
CYCLES IF TIME DELAYS
ARE DESIRED

PERFORM COMPUTATION
FOR ONE RUN

ESTIMATE ACCELERATION
AND ORIFICE AREA 1

COMPUTE VELOCITY,
DISPLACEMENT AND
SPRING FORCE
STORE $A(t)$ AND $A01(t)$
FOR CHECKING CONVERGENCE
$A03(I) = 100$. REPRESENTS INFINITY

COMPUTE ORIFICE AREA 3

$X(I) > 2.75$

TRUE

$X(I) > 0.25$

TRUE

$A03(I) = A03(I) + 13.5*3.14159*0.06*(X(I) - 0.25)/2.50$

FALSE

$AOE(I) = 3.14159*14.4*(0.176 - 0.145*X(I)/11.0)$

$VOL = A0*(X11 - X(I))$

$Q1(I) = AO*V(I) - VOL*(P1(I) - P1(I - 1))/(B*DELT)$

$SQR = 2.0*(P1(I) - P3)/RHO$

FALSE

$X(I) < 2.75$

TRUE

FALSE

$SQR = SQR - (Q1(I)/(CDAO2 + CD3*A03(I)))**2$

$A01(I) = XA01$

1-5
SQR > 0.00000001

TRUE

A01(I) = Q1(I)/SQRT(SQR)

FALSE

P2(I) = P3
Q3(I) = Q1(I)

X(I) > 2.75

TRUE

CDCOE = (((CD102 + CD3*A03(I))/A01(I))**2
P2(I) = (P1(I) + P3*CDCOE)/(1.0 + CDCOE)
Q3(I) = Q1(I)/(1.0 + CD102/(CD3*A03(I)))

FALSE

Q2(I) = Q1(I) - Q3(I)
FJ1(I) = 0.0

JREAC1

TRUE

FJ1(I) = RHO*Q1(I)*(SQRT(2.0*(P1(I) - P2(I))/RHO) - V(I))

FALSE

FJ2(I) = 0.0

1-6

COMPUTE P2(t) AND Q3(t)

COMPUTE Q2(t) AND FLUID-MOMENTUM AT SECTION 1 AND 2
JREAC2

TRUE

FJ2(I) = RHO*Q2(I)*SQRT(2.0*(P2(I) - P3)/RHO)

FALSE

A(I) = (TMEP1 + P2(I)*A2 - P1(I)*(A1 + AO1EX(I)) + FJ1(I) + FJ2(I) - FS(I))/AM

A(I) < 0.0 and X(I) < 0.0

TRUE

SUMFJ(I) = SUMFJ(I-1) + (FJ1(I) + FJ1(I-1) + FJ2(I) + FJ2(I-1))*DELT2

FALSE

Q0(I) = V(I)*A0

NT(I) > NMAX

TRUE

|1.0 - XAOI/AO1(I)| ERR

FALSE

|1.0 - XA/A(I)| ≤ ERR

OR NT(I) < 1

TRUE

50

FALSE

1-7

COMPUTE ACCELERATION A(t)

CHECK CONVERGENCE CONDITION ON ACCELERATION AND ORIFICE AREA
PL(I) ≤ 0.0, or T(I) < 0.045

TRUE

CD1 = A01(I) + CD1
CDLEX = AOLEX(I) + CDLEX

FALSE

OBTAIN AVERAGE DISCHARGE COEFFICIENT

SUMF(I) = SUMF(I-1) + (F(I) + F(I-1)) * DELT2
SUMP1(I) = SUMP1(I-1) + (PL(I) + PL(I-1)) * DELT2 * (A1 + 0.5 * (AOLEX(I) + AOLEX(I-1)))
SUMP23(I) = SUMP23(I-1) + (P2(I) + P2(I-1)) * A2 * DELT2 + P3 * A3 * DELT
SUMF(S) = SUMF(S(I-1)) + (FS(I) + FS(I-1)) * DELT2

QO(I) > QMAX

TRUE

QMAX = QO(I)

FALSE

FIND GREATEST VALUE OF QO(t)

INTEGRATE FORCES WITH RESPECT TO TIME TO OBTAIN IMPULSIVE TERMS
A(I) = A(I - 1)
V(I) = V(I - 1)
X(I) = X(I - 1)
AOLEX(I) = 3.14159 * 14.4 * (0.176 - 0.145 * X(I) / 11.0)
AO1(I) = AOLEX(I)
FJ1(I) = 0.0
FJ2(I) = 0.0
Q0(I) = 0.0
Q1(I) = 0.0
Q2(I) = 0.0
Q3(I) = 0.0
SUMFR(I) = 0.0
SUMF(I) = 0.0
SUMP1(I) = 0.0
SUMP23(I) = 0.0
SUMFJ(I) = 0.0
SUMFS(I) = 0.0

IF A(t) AND X(t) ARE NEGATIVE, OR ZERO (NO NEGATIVE DISPLACEMENT CONDITION)

TOTIMP(I) = SUMF(I) - SUMP1(I) - SUMFS(I) - SUMFR(I) + SUMP23(I) + SUMFJ(I)
XMOM(I) = AM * V(I)
DIFF(I) = (X(I) - XE(I)) / XE(NX)

V(I) < 0.0

TRUE

FALSE

IF VELOCITY LESS THAN ZERO RECOIL STROKE COMPLETED

60

1
\[ CD_{l} = \frac{CD_{l}}{CD_{LEX}} \]

\[ \text{DO 61 } I = 1,NPLOT \]

\[ A01ER(I) = 0.0 \]

\[ P1(I) \leq 0.0 \]

**TRUE**

\[ A01(I) = \frac{A01(I)}{CD_{l}} \]

\[ A01ER(I) = \frac{(A01(I) - A0LEX(I))}{A0LEX(I)} \]

**FALSE**

**AVERAGE DISCHARGE COEFFICIENT**

**COMPUTE ORIFICE AREA USING AVERAGE DISCHARGE COEFFICIENT AND ORIFICE-AREA ERROR**

**PRINT RESULTS**

WRITE-
NR, W, A1, CF, PO, XKS, DELT, CALF, NF, CALP1, NP
CALXE, NX, ERR, NMAX, NDEL, A2, A02, CD1, CD2, CD3
RHO, E, P3, A3, XLL, AO, JREAC1, JREAC2
(T(I), F(I), FS(I), P1(I), P2(I), FJ1(I), FJ2(I),
Q0(I), Q1(I), Q2(I), Q3(I), NT(I), I = NI, NE)
(T(I), A(I), V(I), X(I), XE(I), DIFF(I), A01(I),
A0LEX(I), A0LER(I), AO3(I), I = NI, NE)
(T(I), SUMF(I), SUMF1(I), SUMP23(I), SUMFJ(I),
SUMFS(I), SUMFR(I), TOTIMP(I), XMOK(I), I = NI, NE)

**PLOT RESULTS WITH RESPECT TO TIME**

PLOT-
SUMF(I), SUMF1(I), TOTIMP(I), SUMFR(I), SUMFS(I)
SUMP23(I), SUMFJ(I), DIFF(I), XE(I), X(I), A01(I),
A0LEX(I), Q1(I), Q3(I) AND A0LER(I)
DO 16 J = 1,NF
I = NF + 1 - J
F(I+1) = F(I)

DO 17 J = 1,NPLOT
NT(I) = 0

NF = NF + 1

END

APPLY TIME DELAY TO APPLIED FORCE

REINITIALIZE ITERATION COUNT
Computer Program

C M140 RECOIL MECHANISM WITH A MASSLESS SPRING
C IOWA INSTITUTE OF HYDRAULIC RESEARCH, THE UNIVERSITY OF IOWA

DIMENSION F(200), P1(200), XE(200), X(200), V(200), A(200), T(200), DIFF(1200), NT(200), FS(200), SUMFR(200), SUMF(200), SUMP1(200), SUMPS(200), XM(200), TOTIMP(200), AO1(200), AO3(200), P2(200), SUMP23(200),
3AO1ER(200), AO1EX(200), Q1(200), Q2(200), Q3(200), FJ1(200), FJ2(200),
SUMFJ(200), Q0(200)
LOGICAL JREAC1, JREAC2
READ(5,2000) MAXDFL, NRUN
2000 FORMAT(2I5)
   DO 15 KJ = 1, NRUN
      READ(5,100) CF, XKS, FO, W, B, RHO, JREAC1, JREAC2
100 FORMAT(6F10.5, 2L5)
      READ(5,101) A0, A1, A2, A3, XL1, P3, CD2, CD3, A01ST, A02
101 FORMAT(6F10.5, 1F20.5, 3F10.5)
      READ(5,102) CALF, CALP1, CALXE, DELT, ERR, NMAX, NEND
102 FORMAT(3F10.3, 2F10.8, 2I5)
      READ(5,201) NF, NR, (F(I), I = 2,NF)
201 FORMAT (I5, 1110/(5F10.5))
      READ (5,200) NX,(XE(I), I = 2,NX)
      READ (5,200) NP,(P1(I), I = 2,NP)
200 FORMAT (I5/(5F10.5))
   FG = CF*W
   FG3 = P3*A3 - FG
   AM = W/(32.*2.*12.*0)
   CDA02 = CD2*A02
   DELT2=0.5*DELT
   QMAX = 0.0
   NP1 = NP + 1
   NX1 = NX + 1
   NF1 = NF + 1
   DO 210 J = NP1, NEND
210 P1(J) = 0.0
   DO 211 J = NX1, NEND
211 XE(J) = XE(NX)
   DO 212 J = NF1, NEND
212 F(J) = 0.0
   IF (NX*LT.198.*AND.*NF.*LT.198.*AND.*NP.*LT.198) GO TO 3
   WRITE (6,301)
301 FORMAT (50H NUMBER OF POINTS GREATER THAN DIMENSION STATEMENT)
   GO TO 401
C Initialise Variables
3 X(1)=0.0
   XE(1) = 0.0
   DIFF(1)=0.0
   V(1)=0.0
   A(1)=0.0
   AO3(1)=0.0
   QQ(1) = V(1)*A0
   Q1(1) = AO*V(1)
Q2(1) = Q1(1)
Q3(1) = 0.0
T(1) = 0.0
P1(1) = 0.0
P2(1) = 0.0
FJ1(1) = 0.0
FJ2(1) = 0.0

IF(IJREAC1) FJ1(1) = RHO*Q1(1)*(SQRT(2.0*(P1(1) - P2(1))/RHO) - V(1))

IF(IJREAC2) FJ2(1) = RHO*Q2(1)*SQRT(2.0*(P2(1) - P3)/RHO)

FS(1) = FO
F(1) = 0.0
SUMF(1) = 0.0
SUMP1(1) = 0.0
SUMP23(1) = 0.0
SUMFJ(1) = 0.0
SUMFS(1) = 0.0
SUMFR(1) = CF*W*T(1)
XMOM(1) = AM*V(1)

TOTIMP(1) = SUMF(1) - SUMP1(1) - SUMFS(1) - SUMFR(1) + SUMP23(1) + SUMFJ(1)

DO 2 I=1*NEND

NT(I) = 0
T(I) = DELT*FLOAT(I-1)
F(I) = F(I)*CALF
P1(I) = P1(I)*CALP1

2 XM(I) = XM(I)*CALXE
MXDELI = MAXDELI + 1
DO 15 IJK = 1*MXDELI

AO1EX(I) = AO1ST
AO1(I) = AO1EX(I)
CD1 = 0.0
CD1EX = 0.0
NDEL = IJK - 1
DO 1 I = 2*NEND

NPLT = I
TEMP1 = F(I) + FG3
A(I) = A(I-1)
AO1(I) = AO1(I - 1)

50 NT(I) = NT(I)+1

V(I) = (A(I) + A(I-1)) * DELT2 + V(I-1)
X(I) = (V(I) + V(I-1)) * DELT2 + X(I-1)

FS(I) = FO + XS*X(I)

IF(X(I) * LE. 0.0 AND TEMP1 * LE. 0.0) GO TO 40

XA = A(I)
XA01 = AO1(I)
AO3(I) = 100.
IF(X(I) * GT. 2.75) GO TO 6

AO3(I) = 0.212

IF(X(I) * GT. 0.25) AO3(I) = AO3(I) + 13.5*3.14159*0.06*(X(I) - 0.25)

1/2*50

6 AO1EX(I) = 3.14159*14.4*(0.176 - 0.145*X(I))/11.0

VOL = AO*(XL1 - X(I))
Q1(I) = AO*V(I) - VOL*(P1(I) - P1(I - 1))/(B*DELT)
SQR = 2.0*(P1(I) - P3)/RHO

IF(X(I) * LT. 2.75) SQR = SQR - (Q1(I)/(CDAO2 + CD3*AO3(I)))*2
AO1(I) = XAO1
IF (SQR * GT. 0.000000001) A01(I) = V1(I)/SQR(T(SQR)
P2(I) = P3
Q3(I) = Q1(I)
IF (X(I) .GT. 7.75) GO TO 40
CDCOE = ((CDAO2 + CD3*AO3(I)) / A01(I))**2
P2(I) = (P1(I) + P3*CDCOE)/(1.0 + CDCOE)
Q1(I) = Q1(I)/(1.0 + CDAC2/(CD3*AO3(I)))

40 Q2(I) = Q1(I) - Q3(I)
FJ1(I) = 0.0
IF (JREAC1) FJ1(I) = RHO*Q1(I)*(SQR(T(2.0*(P1(I) - P2(I))/RHO))- V(I)
FJ2(I) = 0.0
IF (JREAC2) FJ2(I) = RHO*Q2(I)*SQR(T(2.0*(P2(I) - P3)/RHO)
A(I) = (TEMP1 + P2(I)*A2 - P1(I)*(A1 + AO1EX(I))) + FJ1(I) + FJ2(I)
1 - FS(I)) / AM
IF (A(I) * LT. 0.0 * AND. X(I) * LE. 0.0) GO TO 40
SUMFJ(I) = SUMFJ(I-1) + (FJ1(I) + FJ1(I-1) + FJ2(I) + FJ2(I-1))*DE

LT2
Q0(I) = V(I) * A0
IF (N(I) * GT. NMAX) GO TO 60
IF (ABS(I) * XAO1/A01(I) * GT. ERR) GO TO 50
IF (ABS(I) * X/A(I) * GT. ERR * OR. N(I) * LE. 1) GO TO 50
IF (P1(I) * LE. 0.0 * OR. T(I) * LT. 0.045) GO TO 42
CD1 = A01(I) + CD1
CD1EX = A01EX(I) + CD1EX

42 SUMFR(I) = CF*W*I(I)
SUMF(I) = SUMF(I-1) + (F(I) + F(I-1)) * DELT2
SUMP1(I) = SUMP1(I-1) + (P1(I) + P1(I-1)) * DELT2*(A1 + 0.5*(A01EX(I) +
1A01EX(I-1)))
SUMP23(I) = SUMP23(I-1) + (P2(I) + P2(I-1)) * A2*DELT2 + P3*A3*DELT
SUMFS(I) = SUMFS(I-1) + (FS(I) + FS(I-1)) * DELT2
IF (Q0(I) * GT. UM) QMAX = Q0(I)
GO TO 41

41 A(I) = A(I - 1)
V(I) = V(I - 1)
X(I) = X(I - 1)
A01EX(I) = 3.14159*14.4*(0.176 - 0.145*X(I)/11.0)
A01(I) = A01EX(I)
FJ1(I) = 0.0
FJ2(I) = 0.0
Q0(I) = 0.0
Q1(I) = 0.0
Q2(I) = 0.0
Q3(I) = 0.0
SUMFR(I) = 0.0
SUMF(I) = 0.0
SUMP1(I) = 0.0
SUMP23(I) = 0.0
SUMFS(I) = 0.0
SUMFJ(I) = 0.0

41 TOTIMP(I) = SUMF(I) - SUMP1(I) - SUMFS(I) - SUMFR(I) + SUMP23(I) + SUMFJ(I)
XMOM(I) = AM*V(I)
DIFF(I) = (X(I) - XE(I))/XE(NX)
IF (V(I) * LT. 0.0) GO TO 60
1 CONTINUE
60 CD1 = CD1/CD1EX
DO 61 I = 1, NPLT
    A01ER(I) = 0.0
    IF(P1(I) <= 0.0) GO TO 61
    A01(I) = A01(I)/CD1
    A01ER(I) = (A01(I) - A01EX(I))/A01EX(I)
61 CONTINUE
WRITE (6,300) NR, A1, CF, FU, KX, DELT, CALF, NF, CALP1, NP
300 FORMAT (1H1,116H BALANCING MOMENTUM OF #140 RECOIL MECHANISM ASSU-
1MING A STATIC SPRING BASIC UNITS ARE POUNDS, INCHES AND SECONDS
2///78H DATA OBTAINED FROM TESTS PERFORMED ON POWDER GYMNASTICAT0
3R ON APRIL 16, 1965///15H RND NUMBER = I4///30H WEIGHT OF RECOILIN
4G PARTS = FA0.0/47H AREA OVER WHICH PRESSURE, P1, IS EFFECTIVE =
5FA3///41H ASSUMED COEFFICIENT OF RAIL FRICTION = FA3///42H SPRIN
6G FORCE IN INITIAL POSITION = FB0.0/32H SPRING CO
7Nstant = FA3///18H TIME INTERVAL = F9.6///25H CALIBRATION OF FORC
8E = FB8.0, 12X24HNUMBER OF POINTS READ = 13///28H CALIBRATION OF P
9RESSURE = FB7.0*/10X24HNUMBER OF POINTS READ = 13)
WRITE (6,305)CALXE, NX, ERR, NMAX, NDEL, A2, AO2, CD1, CD2, CD3
305 FORMAT(32H CALIBRATION OF DISPLACEMENT = F6.3, 6X*24H NUMBER
10F POINTS READ = I4///40H ERROR IN ITERATION ON ACCELERATION IS F1
20.6918H OR A MAXIMUM OF I3*12H ITERATIONS //41H NUMBER OF TIME I
3EAYS ON APPLIED FORCE = I5///34H AREA OVER WHICH P2 IS EFFECTIVE =
4FB8.3///22H AREA OF ORIFICE A02 = F7.4///54H DISCHARGE COEF. OF AO
51, A02, AND A03 ARE RESPECTIVELY 3F10.3/)
WRITE(6,302) RHG, B, P3, A3, XL1, A0, JREAC1, JREAC2
302 FORMAT(21H DENSITY OF FLUID = 1F10.7,26H BULK MODULUS OF FLUID
1 = 1F0.0/16H PRESSURE P3 = 1F6.2*27H AND ACTS OVER AREA (A3)
2 = 1F8.3///39H INITIAL UPSTREAM REGION (XL1 * A0) = 2FB8.3///
322H JET REACTIONS FJ1 = 1L3 /15X, 7H FJ2 = 1L3)
NPE = (NPLT - 1)/50 + 1
DO 10 J=1,NPE
NE=50*J
NI=NE-49
IF(NE.GT. NPLT) NE = NPLT
WRITE (6,400) (T(I), F(I), FS(I), P1(I), P2(I), FJ1(I), FJ2(I),
1 QO(I), Q1(I), Q2(I), Q3(I), NT(I), I = NI, NE)
400 FORMAT (1H1,125H TIME APPLIED SPRING P1 P
12 JET1 JET2 QO Q1 Q2 Q
23 NC/87H FORCE FORCE
3 FORCE FORCE /(1H + F10.5+2F11.0+2F11.2+2F11.3
4, 1F19.0, 3F8.0, 115))
WRITE (6,501) (T(I), A(I), V(I), X(I), XE(I), DIFF(I), AO1(I), AO1EX(I),
1 A01ER(I), AO3(I), I = NI, NE)
501 FORMAT (1H1,131H TIME ACCEL VELOCITY COMP
1 MEAS DISPL ORF AO1 ORF AO1 CD
21 ORF AO3 /131H
3SP DISP ERR CALC COMP DISP
4 ERROR /(1H + 1F12.5+1F12.2+6F12.4+1F24.4+
5 1F11.3))
10 WRITE (6,500) (T(I), SUMF(I), SUMP1(I), SUMP23(I), SUMFJ(I), SUMFS(I),
1 SUMFRI(I), TOTIMP(I), XOMO(I), I = NI, NE)
500 FORMAT (1H1,108H TIME APPLIED SPRING FRICITION NET MOMENTUM/96H
1 JET CD
SCLF = SUMF(NPLOT)
NPL1 = NPLLOT + 1
NPL2 = NPLLOT + 2
T(NPL1) = 0.12
T(NPL2) = 0.17
DIFF(NPL1) = -0.1
DIFF(NPL2) = 0.1
AO1FR(NPL2) = 0.50
AO1FR(NPL1) = -0.50
Q0(NPL1) = -0.1
Q3(NPL1) = -0.1
Q0(NPL2) = 0.1
Q3(NPL2) = 0.1
AO1(NPL1) = 0.0
AO1EX(NPL1) = 0.0
AO1EX(NPL2) = 1.0
AO1(NPL2) = 1.0
XE(NPL1) = 15.0
XE(NPL2) = 0.0
DO 5 I = 1,NPLLOT
5 IF(ABS(DIFF(I)) GE 0.10) DIFF(I) = 0.1*ABS(DIFF(I))/DIFF(I)
DO 4 I = 1,NPLLOT
4 IF(Q0(I) GE 0.0) Q3(I) = Q3(I)/Q0(I)
IF(Q2(I) LE 0.00000001) Q3(I) = 0.0
Q0(I) = (Q0(I) - Q1(I))/QMAX
AO1EX(I) = AO1EX(I)/AO1ST
AO1(I) = AO1(I)/AO1ST
IF(AO1EX(I) GE 1.0) AO1EX(I) = 1.0
IF(AO1(I) GE 1.0) AO1(I) = 1.0
IF(ABS(AO1ER(I)) LE 0.50) AO1ER(I) = 0.5*ABS(AO1ER(I))/AO1ER(I)
IFSUMF(I) LT 0.0) SUMF(I) = 0.0
IFSUMP1(I) LT 0.0) SUMP1(I) = 0.0
IFSUMP23(I) LT 0.0) SUMP23(I) = AAS(SUMP23(I))
IFSUMFS(I) LT 0.0) SUMFS(I) = 0.0
IFSUMFR(I) LT 0.0) SUMFR(I) = 0.0
IFSUMFJ(I) LT 0.0) SUMFJ(I) = 0.0
IF(TOTIMP(I) LT 0.0) TOTIMP(I) = 0.0
IF(ABS(Q0(I)) GE 0.10) Q0(I) = 0.1*ABS(Q0(I))/Q0(I)
IF(ABS(Q3(I)) GE 0.10) Q3(I) = 0.1*ABS(Q3(I))/Q3(I)
IF(ABS(AO1ER(I)) GE 0.5) AO1ER(I) = 0.5*ABS(AO1ER(I))/AO1ER(I)
SUMF(I) = SUMF(I)/SCLF
SUMP1(I) = SUMP1(I)/SCLF
SUMP23(I) = SUMP23(I)/SCLF
SUMFS(I) = SUMFS(I)/SCLF
SUMFR(I) = SUMFR(I)/SCLF
SUMFJ(I) = SUMFJ(I)/SCLF
4 TOTIMP(I) = TOTIMP(I)/SCLF
SUMF(NPL1) = 0.0
SUMP1(NPL1) = 0.0
TOTIMP(NPL1) = 0.0
SUMFR(NPL1) = 0.0
SUMFS(NPL1) = 0.0
SUMFJ (NPL1) = 0.0
SUMP23(NPL1)=0.15
WRITE(6,'1000') NR, NDFL
1000 FORMAT(60H1 TIME VERSUS APPLIED IMPULSE (+), PRESSURE IMPULSE (X)
1 TOTAL IMPULSE (*), FOR ROUND NO. 13/45H AND NUMBER OF TIME DELAYS ON APPLIED FORCE = I5)
CALL LPLT(NPL1, T(1), SUMP(1), SUMP1(1), TOTIMP(1))
WRITE(6,'1002') NR, NDFL
1002 FORMAT(119H1 TIME VERSUS FRICTION IMPULSE (Y), SPRING IMPULSE (+),
1 DWN. PRESS. IMPULSE (X), NET FLUID MOMENTUM (*), FOR ROUND NO.
2113/45H AND NUMBER OF TIME DELAYS ON APPLIED FORCE = I5)
CALL LPLT(NPL1, T(1), SUMFR(1), SUMFS(1), SUMP23(1), SUMFJ(1))
WRITE(6,'1001') NR, NDFL
1001 FORMAT(121H1 TIME VERSUS DISPLACEMENT ERROR IN TERMS OF TOTAL REC)
1/ 15H FOR ROUND NO. 113, 45H AND NUMBER OF TIME DELAYS ON APPLIED
3 FORCE = 115)
CALL LPLT(NPL2, T(1), DIFF(1))
WRITE(6,'1022')
1022 FORMAT(56H1 EXPERIMENTAL DISPLACEMENT(X), COMPUTED DISPLACEMENT(*)
1)
CALL LPLT(NPL1, T(1), XE(1), X(1))
WRITE(6,'1023')
1023 FORMAT(56H1 EXPERIMENTAL ORIFICE AREA(*), COMPUTED ORIFICE AREA(X)
1)
CALL LPLT(NPL2, T(1), AO1(1), AO1EX(1))
WRITE(6,'1024')
1024 FORMAT(56H1 (Q0 - Q1)/QMAX (X), AND Q3/Q0(1) (*))
CALL LPLT(NPL2, T(1), Q0(1), Q3(1))
WRITE(6,'1025') NR, NDFL
1025 FORMAT(53H1 ORIFICE AREA IN TERMS OF IN-BATTERY ORIFICE AREA
2/ 15H FOR ROUND NO. 113, 45H AND NUMBER OF TIME DELAYS ON APPLIED
3 FORCE = 115)
CALL LPLT(NPL2, T(1), AO1ER(1))
DO 16 J = 1, NF
I = NF + 1 - J
16 F(I + 1) = F(I)
DO 17 J = 1, NPLT
17 NT(IJ) = 0
15 NF = NF + 1
401 CALL EXIT
END
A Preliminary Analysis of the M140 Recoil Mechanism

Technical Report

Arthur D. Newsham, Enzo O. Macagno, and Tin-Kan Hung

December 1966

DA-11-070-508-ORD-988

Report No. 100

Each transmittal of this document outside the Department of Defense must have prior approval of the R. & E. Division, Rock Island Arsenal.

Rock Island Arsenal

The equations of motion for the recoil phase of the M140 Recoil Mechanism have been formulated. This mechanism contains a coil spring, the action of which has been represented in a static manner in this preliminary analysis. The system of equations has been solved by reducing it to a system of difference equations. The results of the analysis are compared with data obtained from a series of experiments performed in a powder gymnasticator at the Rock Island Arsenal. The relative effect of the various parameters influencing the motion of the recoiling parts is presented in a systematic manner. A series of graphs show the relative error in the displacement of the recoiling parts of the mechanism due to variations of several parameters. According to the computational model, the effect of deviations in the values of the bulk modulus of elasticity of the hydraulic oil, the spring constant, and the rail-friction coefficient are rather small. On the other hand, the time delay, the downstream pressure, and the reaction of internal jets have a larger influence.
<table>
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<th>KEY WORDS</th>
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