In many gun accuracy investigations the projectile as well as the muzzle dynamics during shot exit must be determined. Not every instrumentation used for gun barrel motion measurements is suitable for the obtainment of the muzzle motion due to temporal resolution and spatial accuracy requirements. An instrumentation referred to as the Schmidt Displacement Transducer (SDT) has recently been developed at the Ballistic Research Laboratory which is well suited for these type of measurements. This report contains a brief review (continued on next page)
20. (continued)

of instrumentation applicable to the measurement of barrel and muzzle motion, a description of the SDT instrumentation and its application for monitoring muzzle motion, an analysis procedure for SDT type of data for extracting the muzzle motion with respect to the ground, and the developed computer data analysis program with appropriate examples.
TECHNICAL REPORT BRL-TR-2872

ANALYSIS PROCEDURE FOR MUZZLE MOTION DATA COLLECTED WITH THE SCHMIDT DISPLACEMENT TRANSDUCER INSTRUMENTATION

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1. INTRODUCTION

Gun accuracy essentially encompasses the complete delivery mechanism of one or many projectiles fired from a gun to a target intercept space-time volume so that the warhead will be able to defeat the target. The main thrust of the ongoing US work is directed toward tank gun accuracy and projectile launch integrity in order to increase the hit probability of our tank fleets. Much of this involves product improvement of fielded weapons and development support for new systems. Hence, most of the work involves system engineering and analysis and is hardware related and, as such, is classified. The Ballistic Research Laboratory (BRL) is in the process of actively exploiting innovative ideas and concepts to assure that projectiles will leave the muzzle in the proper aim direction by reducing the gun related variation of projectile launch parameters to that obtained when firing from precision mounts. To support these tasks and develop the appropriate technology base, BRL is pursuing a basic research program which addresses, among other technology areas, the projectile launch from the gun.

In particular, we are concerned with the sources and mechanisms which cause the bias of the impact point relative to the target as well as with the errors and impact distribution due to parameter variations. For all practical purposes, the effect of exterior ballistic related sources as well as the propagation of variations in the launch parameters on the projectile flight trajectory are well understood and predictable with sufficient accuracy. Contrarily, the sources and processes which determine the variation of the projectile launch parameters are least understood. Though a reasonable qualitative understanding exists, quantitative relationships remain a problem. Unfortunately, a methodology correlating projectile and gun parameters with the projectile dynamics immediately after projectile release from the muzzle and satisfying the needs of quantitative analysis has not been developed yet. To remove this obstacle and to develop the required methodology for a quantitative simulation of projectile launch, BRL is pursuing a multi-pronged approach including both theory and experiment. The experimental program addresses both the validation of gun system accuracy models under development and the improvement of our diagnostic capability. One part focuses on the investigation of the disengagement mechanism of the projectile from the cannon. This includes the adaptation of available instrumentation and measurement techniques along with the development of new ones suitable for the measurement of the muzzle motion with the appropriate temporal and spatial resolution and without any interference to the projectile and gun dynamics. The muzzle dynamics is intrinsically connected to the projectile motion, i.e., muzzle aim, transverse velocity and angular rotation during shot exit are manifested in and reflect the projectile launch parameters.

Most of the instrumentation and measurement techniques for monitoring gun barrel motion are directly applicable to the measurement of the six degrees-of-freedom motion of the muzzle section of the gun barrel. A brief review of barrel motion measurement techniques is provided in Appendix A. Unfortunately, there are certain difficulties involved in selecting the appropriate measurement techniques and combining them into an instrumentation setup which allows the extraction of the six degrees-of-freedom motion of the muzzle with the required accuracy from the observables. For instance, the effect of longitudinal and radial stress waves produced in the tube by the
traveling projectile and combustion gas pressure as well as the abrupt decorking of the tube is largest at the muzzle end and manifests itself in the recoil motion of the muzzle as the projectile moves through it. We have observed short time reductions of the muzzle recoil velocity by more than one fourth from its value prior to shot exit. Therefore, the recoil motion must be measured directly at the muzzle and cannot be inferred from measurements at other locations. Also, because of the high frequency content of these stress waves, the use of piezoelectric accelerometers mounted on the outer surface of the cannon may not be expedient for the measurement of the axial and the transverse muzzle motion. Other instrumentation, such as the electrooptical or electromagnetic displacement sensors, must be employed which do not interfere with the projectile or the tube motion and are not affected by the radial vibrations of the tube and the precursor-blast environment. In addition, a time resolution on the order of microseconds or less and a spatial resolution on the order of microns are desirable to adequately describe projectile exit phenomenology.

The Schmidt displacement transducer (SDT) instrumentation and measurement technique recently developed at BRL for the determination of the projectile motion during shot exit [1][2][3][4] can also be applied to the measurement of the muzzle motion. This displacement transducer can provide data which, after the appropriate data analysis, allow the determination of five parameters of the six degrees-of-freedom motion of the muzzle. Only the rotation about the bore axis cannot be determined. The technique has been applied and checked in a recent experiment [5][6] and, subsequently, has been employed in a tank gun accuracy firing test to obtain the muzzle aim at shot exit.

This report contains a brief description of the SDT (Section 2.) and discusses the data analysis concept and procedure (Section 3.) which form the basis of the computer program (Section 4.). The data used for illustrating the analysis program are from the cited experiments.

2. SDT INSTRUMENTATION AND MEASUREMENT TECHNIQUE

The Schmidt displacement transducer for monitoring transverse displacements (Figure 2.1) as well as its function are described in Reference [4]. As shown, the SDT consists of two pairs of semicircular inductors peripherally connected to an oscillator and concentrically arranged in a ring configuration, ninety degrees apart. This ring is placed concentric with and perpendicular to the tube axis at the desired measurement location, thus establishing an electromagnetic coupling between the active sensor and the conducting tube surface. The currents from each sensor pair are fed to a low-gain differential amplifier and its output is then amplified to a suitable level for recording. The polarity and magnitude of these currents are a direct measure of the direction and the magnitude of the closeness of the outer barrel surface to the two semicircular inductors and, when calibrated, yield the appropriate transverse displacement of the tube relative to the electromagnetic center of the SDT ring. Employing two or more SDT systems at the muzzle allows the pointing vector of the muzzle to be extracted from the displacements. The functional relationship between the measured voltages and the corresponding transverse displacements has been found to be:
Figure 2.1. Sensor Arrangement And Block Diagram Of Electronic Circuit Of The SDT

\[ x = \frac{V_x}{a_0 \sqrt{1 + a_1 x^2 + a_2 y^2}} \quad , \quad y = \frac{V_y}{b_0 \sqrt{1 + b_1 x^2 + b_2 y^2}} , \quad (2.1) \]

where \( V_x \) and \( V_y \) denote voltage and \( x \) and \( y \) the corresponding displacements. The coefficients occurring in these relations will vary from setup to setup and must be determined prior to each firing experiment. Since the sensor rings are considerably lighter than the cannon, the calibration is best done by mounting the sensor ring on positioning devices and displacing the sensor with respect to the resting cannon.

The axial or \( z \)-component of the tube motion can also be obtained by employing the SDT technique. This, however, requires that the exterior cannon surface be modified. This is achieved by alternating spatially either the radius or the electric conductivity of the outer surface of the cannon. Though, in principle, the sum signal from the SDT system can be used directly for monitoring the translation in the \( z \)-direction, it is advisable to separate the measurement of the \( z \)-displacement from that of \( x \) and \( y \). Two sensor designs in which unwanted contributions from the transverse and rotational
tube motion are sufficiently suppressed are practicable: one consisting of four individual sensor loops ninety degrees apart, aligned parallel with the tube axis with the four signals summed (Figure 2.2 (a)) and the other consisting of a single loop arranged concentrically around the tube (Figure 2.2 (b)). The relationship between the recorded voltage and the corresponding displacement is given by

\[ Z = Z_{i+1} + \Delta Z_i \left[ \frac{1}{2} + \frac{1}{\pi} \arcsin \frac{V(t)}{E_{i+1} - E_i} \right], \]

\[ \zeta = 2 \frac{V(t) - E_i}{E_{i+1} - E_i}, \quad V(t) \in (E_{i+1}, E_i), \]  

(2.2)

Figure 2.2. Sensor Arrangement And Signal-Displacement Correlation For The SDTz
where $Z_{i+1}^j$ is the accumulated recoil displacement up to the extremum $E_{i+1}$ and $\Delta Z_i$ the distance between the extrema $E_{i+1}$ and $E_i$. The coefficient of the polynomial $P_i(\zeta)$ may vary from interval to interval and must be determined prior to the firing experiment. The width of the periodic bands, $w$, depends on the design and the accuracy requirement. For the four sensor loop design $w$ should be a full or one-third sensor length and for the single sensor loop design $w$ should be about the mean distance from the sensor ring to the cannon surface. From the analysis point of view, the highest accuracy and linearity should occur during shot exit. This requires that the initial location of the sensor at shot start be selected such that its location at shot exit is in the vicinity of $\sin P(\zeta) = 0$ or, equivalently, the band edge should be close to the center plane of the sensor. Since radial tube expansion and contraction may slightly shift the signal level, $w$ should be short enough to include the recording of the extrema enclosing the measurement interval of interest, thus allowing self-adjusting conversion of the signal.

Special care has to be taken in the mounting arrangement for the SDT rings in order that neither the muzzle blast nor the counterrecoiling muzzle will damage the instrumentation. In firing tests with tank guns it has been found that it is best to physically disconnect the sensor rings from the mounts after the projectile has left the muzzle and let them freely move with the recoiling gun. For small caliber guns, this provision is not necessary.

3. DATA ANALYSIS CONCEPT AND PROCEDURE

As pointed out earlier, the desire for gun accuracy is the driving force behind most of our cannon motion measurements. These measurements must provide data which allow the correlation of target location, aiming point of muzzle after laying the gun (shot start), aiming point and transverse as well as angular velocity of muzzle at shot exit, initial free flight motion of projectile, and target impact location. The obtaining of appropriate muzzle motion-related parameters for direct fire weapons mounted on resting platforms is addressed here.

3.1. Experimental Arrangement

It is presumed that the transverse displacements of the muzzle section of the cannon is monitored at $m$ locations, where $m$ is at least two, and the muzzle recoil at $m'$ locations, where $m'$ is at least one, with sensors which measure these displacements with respect to the ground (Figure 3.1). An $m=3$ and $m'=2$ system is currently being developed at BRL, consisting of three transverse SDT units about three bore diameters apart and two axial single loop SDT units located in between to measure five of the six degrees-of-freedom. Only the rotation of the tube about its main axis is not obtainable. Though the data analysis is general, it has been developed with this particular case in mind.

*) An upcoming BRL-MR by J.O. Schmidt and T.L. Brosseau will describe a mounting arrangement for the SDT rings which was successfully employed in a recent tank gun accuracy experiment.
Figure 3.1. Sensor Locations For Monitoring Muzzle Motion

It is further assumed that the instrumentation is completely decoupled from the gun and its platform; i.e., work on the gun can be done without any disturbance of the sensors. The frame of reference provided by the array of sensors must stay the same from the time the gun is layed until the shot has left the muzzle. This requirement allows one to relate the position of the tube axis at the individual measurement locations to a reference line established prior to the actual firing and to calibrate the muzzle-pointing vector as obtained from the sensors to the aiming point established by bore sighting (Appendix B).

3.2. Analysis Procedure

It is presumed that the recorded signals have been converted into voltages by accounting for the appropriate calibration for the total instrumentation and recording chain and are arranged into time series with a common time basis,

\[ V(v, \mu, \lambda), v = 1, 2, \mu = 1, 2, \ldots, m, \lambda = 1, 2, \ldots, \ell, \]
\[ V(3, \mu', \lambda), \mu' = 1, 2, \ldots, m', \lambda = 1, 2, \ldots, \ell, \]

where \( \lambda \) is the index for the discrete time \( t = \lambda \Delta t \), \( \Delta t \) is the time increment, and \( \ell \) is the length of the available data window.

3.2.1. Data Conversion

These voltages are then converted into displacements using the appropriate mapping correlation. For the transverse SDT signals we have, according to Eq. (2.1),
\[ S(v, \mu, \lambda) = \frac{V(v, \mu, \lambda)}{\sqrt{1 + C_{V}V(1, \mu, \lambda)^2 + C_{V}V(2, \mu, \lambda)^2}} \]

\[ S(v, \mu, \lambda) = S(v, \mu, \lambda) - S_{0}(v, \mu), \]

\[ v = 1, 2, \mu = 1, 2, \ldots m, \lambda = 1, 2, \ldots l, \]

where \( S(v, \mu) \) is an alignment function as defined in Appendix B. The locations along the tube, \( Z(\mu) = Z(\mu, \lambda) \), where these transverse displacements are recorded, move with the tube axially and are computable from the axial SDT signals. Their conversion into displacement, though more complex, is also straightforward if one follows the procedure sketched below.

0 find the extrema of the time series \( V(3, \mu', \lambda), \lambda = 1, 2, \ldots l, \) and their corresponding times

\[ \hat{E}(\mu', j), \hat{\lambda}(j) = \lambda_{j}, j = 1, 2, \ldots J_{\mu}, \]

0 \( \forall j, j \in [1, 2, \ldots J_{\mu}] : \)

0 for \( j = 1 : \)

identify the \( z \)-interval to which \( \hat{E}(\mu', 1) \) belongs \( + i = \mu' \),

let \( \Delta E = E_{i} - E_{i+1} \), where \( E_{i} - E_{i+1} \) is taken from calibration, and

set \( A = E(\mu', 1) - \Delta E, Z_{o} = 0, \Lambda = 0 \)

0 let \( \Delta Z = Z_{i} - Z_{i+1}, \) where \( Z_{i} - Z_{i+1} \) is given by the calibration, and

set \( B = A, A = E(\mu', j), \Lambda_{o} = \Lambda + 1, \Lambda = \hat{\lambda}(j) \)

0 \( \forall \lambda, \lambda \in [\Lambda_{o}, \Lambda] : \)

let \( \zeta = 2[V(3, \mu', \lambda) - R]/[A - B] - 1 \)

and compute

\[ S(3, \mu', \lambda) = Z_{o} + \Delta Z[ \frac{1}{2} + \frac{1}{\sqrt{1 - P(\zeta)}}] \]

*) FORTRAN type substitution statements are used throughout.

**) Special notation is being used where the symbols have the following meaning: \( \forall \ldots \) for all and \( \in \ldots \) from the interval
0 if $j=1$: subtract $S(3, \mu', 1)$ from the calculated displacements to equate the $z$-displacement at shot start to zero

$\forall \lambda, \lambda \in [1, \hat{\lambda}(1)]: S(3, \mu', \lambda) = S(3, \mu', \lambda) - S(3, \mu', 1)$

0 set $Z_0 = S(3, \mu', \hat{\lambda}(j))$ and $i=i-1$ to provide the initial displacement and identification for the next $z$-interval (3.3)

3.2.2. Modeling Of Muzzle Flexure

To develop the above mentioned data analysis algorithm which allows the extraction of five of the six degrees-of-freedom motion parameters from the time series, we have to make certain model assumptions.

The tube flexure near the muzzle end ($z=0$) may be modelled as a polynomial of $k$-th order in $z$:

$$S(v, z, \lambda) = \sum_{\nu=1,2, \lambda=1,2...k} C(\nu, \lambda) z^\nu.$$  

(3.4)

For the end conditions for a free beam at $z=0$ we may assume zero bending moment as well as zero shearing force. Thus,

$$[EIS''][z=0] = 0 \Rightarrow S''(v, 0, \lambda) = 0, \text{ and}$$

(3.5)

$$[EIS'''][z=0] = 0 \Rightarrow S'''(v, 0, \lambda) = 0, \text{ (3.6)}$$

where Eq. (3.5) is the expression for bending moment, Eq. (3.6) the expression for shearing force, $E$ Young's modulus of elasticity and $I = I(z)$ the moment of inertia. From that we have the requirement that

$$C(2, \nu, \lambda) = C(3, \nu, \lambda) = 0 \text{ and } k < \mu+1.$$  

(3.7)

As the gun barrel recoils, the sensor locations with respect to the muzzle face will vary with the recoil as

$$z(\mu, \lambda) = z_0(\mu) + \int d\lambda \, \dot{z}(z, \lambda), \mu = 1,2,...m, \text{ (3.8)}$$

where $\dot{z}(z, \lambda)$ is the recoil velocity of the muzzle which is obtainable from the $S(3, \mu', \lambda), \mu'=1,2,...m'$. Because these recoil displacements are not
recorded at the locations \( z(\mu), \mu = 1, 2, \ldots m \), and because the tube response to the travelling projectile and combustion gas pressure is large and transient at the muzzle, straightforward linear inter- or extrapolation may not be expedient, especially if the muzzle motion is to be determined with very high accuracy.

The recoil velocity at the locations \( z(\mu') \) may be computed by convoluting the time series \( S(3, \mu', \lambda) \) with an appropriate FIR (finite impulse response) differentiator \( D(\lambda') \) [7],

\[
\ddot{S}(\mu', \lambda) = \sum_{\lambda'} D(\lambda') S(3, \mu', \lambda - \lambda') , \quad \mu' = 1, 2, \ldots m', \quad \lambda = 1, 2, \ldots \ell . \quad (3.9)
\]

This velocity history (Figure 3.2) consists of a trend describing the gross recoil motion of the tube at that particular location and a square well-like modulation derived from the transient in-bore loads. The arrows show the behavior of the well as the measurement location is moved towards the muzzle face: the width enveloping the shot exit time narrows and the depth increases. The left wall correlates to the passage of the rotating/driving band of the projectile travelling towards the muzzle and the right wall to a tube stress relaxation wave produced by the decorking of the pressurized tube and travelling from the muzzle back to the breech. To separate the gross

---

**Figure 3.2. Muzzle Recoil Velocity**
recoil velocity and the well-like modulation in the presence of noise, we may proceed in the following way:

\( \forall \mu', \mu' \in [1,2, \ldots, m'] : \)

0 Compute an upper and lower envelope of the data, their difference, and their maximal and mean values:

\[ \Delta \hat{S} = \Delta \hat{S} = 0 \]

\( \forall \lambda, \lambda \in [\Delta \lambda + 1, \ldots, \ell - \Delta \lambda], \) where \( 2 \Delta \lambda + 1 \) is the arc length,

\[ \hat{S}^+(\mu', \lambda) = \max\{\hat{S}(\mu', \lambda - \Delta \lambda), \ldots, \hat{S}(\mu', \lambda + \Delta \lambda)\} \quad \text{...upper bound} , \]

\[ \hat{S}^-(\mu', \lambda) = \min\{\hat{S}(\mu', \lambda - \Delta \lambda), \ldots, \hat{S}(\mu', \lambda + \Delta \lambda)\} \quad \text{...lower bound} , \]

\[ \Delta \hat{S}(\mu', \lambda) = \hat{S}^+(\mu', \lambda) - \hat{S}^-(\mu', \lambda) \quad \text{...difference} , \]

\[ \Delta \hat{S}_{\text{max}} = \max\{\Delta \hat{S}_{\text{max}}', \Delta \hat{S}(\mu', \lambda)\} \quad \text{...maximum} , \]

\[ \Delta \hat{S} = \Delta \hat{S}_{\text{max}} + \Delta \hat{S}(\mu', \lambda) , \]

\[ \Delta \hat{S} = \Delta \hat{S}/(\ell - 2\Delta \lambda) \quad \text{...mean} . \]

The behavior of the resulting function is illustrated in Figure 3.3.

![Figure 3.3. Determination Of Well Boundaries](image-url)
Determine the times $\lambda^-$, $\lambda^+$, $\lambda^{++}$, and $\lambda^{+-}$ at which the difference curve intersects the line $\Delta \hat s = (\Delta \hat s_{\text{max}} + \Delta \hat s)/2$ and compute from them the time locations of the left and right well boundaries, $\lambda^- (\mu') = 1/2 (\lambda^- + \lambda^{+-})$ and $\lambda^+ (\mu') = 1/2 (\lambda^{+-} + \lambda^{++})$.

Using spline fitting or least squares (LSQ) technique, set forth a function (e.g., a sequence of cubic splines or a higher order polynomial) such that

$$f(\mu', \lambda) \overset{\text{LSQ}}{=} \{ \hat s(\mu', \lambda) \} \text{ for } \lambda < \lambda^- (\mu') \text{ and } \lambda > \lambda^+ (\mu')$$

where $f(\mu', \lambda)$ now describes the gross recoil velocity. Subtraction of this function from the data yields a time series which contains the leftover noise and the well-like modulation:

$$\Delta \hat s(\mu', \lambda) = \hat s(\mu', \lambda) - f(\mu', \lambda), \lambda = 1, 2, \ldots, k$$

Using a LSQ procedure, the depth of the well can be obtained

$$g(\mu', \lambda) = \text{def } g_0 + g_{1, \lambda} \overset{\text{LSQ}}{=} \{ \Delta \hat s(\mu', \lambda) \}, \lambda \in [\lambda^- (\mu') + \delta \lambda, \lambda^+ (\mu') - \delta \lambda].$$

With that, the decomposition of the individual velocity signal into a gross recoil velocity and a time dependent well-like modulation is completed,

$$\hat s(\mu', \lambda) = f(\mu', \lambda) + e(\lambda - \lambda^- (\mu')) e(\lambda^+ (\mu') - \lambda) g(\mu', \lambda) + n(\mu', \lambda),$$

where $e(x) = 0$ for $x < 0$ and $e(x) = 1$ for $x > 0$ and $n(\mu', \lambda)$ is the remainder after subtracting the gross recoil velocity and the well from the data.

From these individual functions a new function describing the recoil motion of the muzzle relative to the instantaneous measurement location $z(\mu' = 1, \lambda)$ can be derived:

$$z(\zeta, \lambda) = F(\zeta, \lambda) + e(\lambda - \lambda^- (\zeta)) e(\lambda^+ (\zeta) - \lambda) G(\zeta, \lambda),$$

where

$$F(\zeta, \lambda) = \text{def } \sum_{k'} \sum_{k} f_{(\lambda)} \zeta^k \overset{\text{LSQ}}{=} \{ f(\mu', \lambda) \},$$
for \( k' < (m'-1) \), \( \zeta = z - z(\mu' = 1, \lambda) \) and \( \zeta(\mu') = z_0(\mu') - z_0(1) \).  \hspace{1cm} (3.10)

By continuously updating the location of the muzzle we can obtain the translation of this location relative to the resting frame of reference:

\[
\begin{align*}
\zeta &= z - z_0(1), \quad \zeta = \dot{z}(\zeta, 1) \quad \text{... initial location and velocity with respect to } z_0(\mu' = 1) \\
\forall \lambda, \lambda &\in [2, \ldots, \ell]: \\
\zeta &= \zeta + \Delta \lambda \dot{\zeta} \\
\ddot{\zeta} &= \dot{z}(\zeta, \lambda) \\
\ddot{z}(\lambda) &= z_0(1) + \zeta \\
\ddot{z}(\lambda) &= \zeta
\end{align*}
\hspace{1cm} (3.11)

Setting \( z = z(\mu), \mu = 1, 2, \ldots, m \), provides the cannon recoil motion at the sensor locations which monitor the transverse muzzle displacements. Insertion of the appropriate quantities into Eq. (3.4) yields a set of algebraic equations,

\[
\begin{align*}
&\begin{array}{c}
1 \\
1 \\
\vdots \\
1 \\
\end{array}
\begin{array}{c}
z(1, \lambda) z^\prime(1, \lambda) \ldots z^k(1, \lambda) \\
z(2, \lambda) z^\prime(2, \lambda) \ldots z^k(2, \lambda) \\
v \\
z(m, \lambda) z^\prime(m, \lambda) \ldots z^k(m, \lambda)
\end{array}
\begin{array}{c}
\ddot{C}(0, \nu, \lambda) \\
\ddot{C}(1, \nu, \lambda) \\
\ddot{C}(4, \nu, \lambda) = \\
\ddot{C}(k, \nu, \lambda)
\end{array}
\begin{array}{c}
S(\nu, 1, \lambda) \\
S(\nu, 2, \lambda) \\
\ldots \\
S(\nu, m, \lambda)
\end{array}
\end{align*}
\hspace{1cm} (3.12)

from which the coefficients \( C(\kappa, \nu, \lambda), \kappa = 0, 1, 4, \ldots, k < \mu + 1 \), can be computed either directly, if \( k = \mu + 1 \), or via LSO, if \( k < \mu + 1 \).
3.2.3. Translation And Rotation Parameters

The translation of a point lying on the muzzle axis with respect to the ground frame of reference is

\[
S(v, z, \lambda) = \sum_{\nu=1,2}^{k} C(\kappa, \nu, \lambda) z(\lambda)^{\nu}, \quad \lambda = 1,2, \ldots, l.
\]

(3.13)

One can now obtain its linear transverse velocity by convoluting the time series with an appropriate FIR differentiator:

\[
S'(v, z, \lambda) = \frac{d}{d\lambda} S(v, z, \lambda) = \sum_{\lambda'} D(\lambda') S(v, z, \lambda - \lambda'), \quad \nu = 1,2, \quad \lambda = 1,2, \ldots, l.
\]

(3.14)

The linear axial velocity \(S(3, z, \lambda) = z(\lambda)\) is given by Eq. (3.11).

The slope of the muzzle at position \(z\) is given by

\[
S'(v, z, \lambda) = \frac{d}{dz} S(v, z, \lambda) = \sum_{\nu=1,2}^{k} C(\kappa, \nu, \lambda) z(\lambda)^{\nu-1}, \quad \nu = 1,2, \lambda = 1,2, \ldots, l.
\]

(3.15)

From Eq. (3.15) and neglecting any rotation of the tube axis we can determine the axes of the moving coordinate system which is located at the axial location \(z\) (Figure 3.4) relative to the ground frame of reference

\[
\hat{e}_1'(\lambda) = \frac{1}{u} (1, 0, -s_1'), \quad \hat{e}_2'(\lambda) = \frac{1}{uv} (-s_1's_2', 1+s_1'^2, -s_2'),
\]

\[
\hat{e}_3'(\lambda) = \frac{1}{v} (s_1', s_2', 1), \quad \text{where}
\]

\[
u = \sqrt{1 + s_1'^2}, \quad v = \sqrt{1 + s_1'^2 + s_2'^2},
\]

\[
1 = s_1'(1, z, \lambda), \quad s_2' = S'(2, z, \lambda), \quad \text{and}
\]

\[
\lambda = 1, 2, \ldots, l.
\]

(3.16)

The axis given by \(\hat{e}_3'\) may also be described by two successive rotations \(\theta\) and \(\phi\) relative to the reference axis. The expression for \(\theta\) and \(\phi\) in terms
of the instantaneous tube axes are

\[ \theta(\lambda) = \arcsin \left[ \sqrt{e_{31}^2 + e_{32}^2} \sqrt{1 + e_{31}^2 + e_{32}^2} \right] , \]

\[ \phi(\lambda) = \arccos \left[ e_{32} \sqrt{e_{31}^2 + e_{32}^2} \right] , \]

where \( e_{31}^i = e_{31}(\lambda) \), \( e_{32}^i = e_{32}(\lambda) \), \( \lambda = 1, 2, \ldots, \ell \) .

(3.17)

Figure 3.4. Rotation Of Tube Axis With Respect To Ground Reference System

The rate of change of \( \theta \) and \( \phi \) may be determined by numerical differentiation:

\[ \dot{\theta}(\lambda) = \sum_{\lambda'} D(\lambda') \theta(\lambda-\lambda') \text{ and } \dot{\phi}(\lambda) = \sum_{\lambda'} D(\lambda') \phi(\lambda-\lambda') . \]

(3.18)

Having determined the translation and rotation of a coordinate frame centered on the muzzle axis we can express any vector given with respect to a moving coordinate system as a vector with respect to the ground frame of reference as

\[ V(v, \lambda) = S(v, z, \lambda) + \sum_{v'} V(z; v', \lambda) e_{v'}^i , \quad v=1, 2, 3, \lambda=1, 2, \ldots, \ell . \]

(3.19)

It should be noted that the derived quantities depend on the initial gun curvature which is very seldom obtained experimentally. Equating \( S(v, \mu) \), \( v=1, 2 \) and \( \mu=1, 2, \ldots, m \), in Eq. (3.2) to the mean value of the displacement time series before any motion occurs, the above equations describe the temporal change in the displacements with respect to the unknown initial tube flexure. Because of the free end conditions of the tube at the muzzle face the
equations will yield the correct motion at the muzzle end regardless of the
downtube curvature before shot start.

4. OUTLINE AND DESCRIPTION OF COMPUTER PROGRAMS

4.1. General Description

The BRL CYBER computer system consists of three mainframes: mainframe
A(MFA), which is a CYBER 750, mainly used for input/output, mainframe P(MFB),
a CYBER 825, for computer graphics, and mainframe Z(MFZ), a CYBER 7600, for
floating point computations. In addition, MFA and MFB share a common file
space and both use the NOS operating system. MFZ, though, uses the SCOPE
operating system. The commercial package DISSPLA [8] was chosen to generate
the plots. Version 8.2 of DISSPLA is resident on all mainframes, while
Version 9.0 is available only on MFA and MFB. Plots are available on a
CALCOMP plotter or a printer attached to an interactive terminal (in this
case, a TEKTRONIX 4695 printer interfaced to a Tektronix 4107 terminal). One
computer program uses the International Mathematical and Statistical Library
(IMSL) [9], which is also available on all mainframes.

The data analysis computer package consists of two programs, MUZMO40 and
MUZPRED, both written in FORTRAN IV. The first program is a preprocessor and
the second one does the actual computations. Program MUZMO40 inputs the raw
data (in counts), converts the data into engineering units and then filters
and/or differentiates the data. The input data are assumed to be on a data
file. In our case, a Nicolet oscilloscope is interfaced with a Hewlett-
Packard 9845C microcomputer which, in turn, communicates with the BRL CYBER
computer system. The data are retrieved from the Nicolet disk, stored on the
HP9845C disk, and then transferred to a file on MFA. This transfer is
described in Reference [10]. The output data file from the first program is
then used as an input to the second program.

Listings of the programs, the job control language (JCL) to run the
programs, descriptions and formats for the input data and a sample case along
with sample input and output are given in Appendices C and D.

![Flowchart for Program MUZMO40](image)

Figure 4.1. Flowchart For Program MUZMO40
4.2. Computer Program MUZM040

The flowchart for MUZM040 is shown in Figure 4.1. The main program calls the subroutines in proper sequence as determined by the input control variables: IPLT1, IPLT2, IPLT3, and IPRT. If the control variable equals 1, the operation is done; otherwise, not. IPLT1 controls the plotting of the displacements; IPLT2 controls the plotting of the velocities; IPLT3 controls the plotting of the accelerations; and IPRT controls the saving of the processed data for future use.

4.2.1. Subroutine COEFL

This subroutine inputs the coefficient array and other necessary parameters of a previously generated FIR lowpass or highpass filter.

4.2.2. Subroutine COEF2

This subroutine inputs the coefficient array and other necessary parameters of a previously generated FIR differentiator.

4.2.3. Subroutine CONVOL

This subroutine does a linear convolution of the NFILT coefficients with a data array of length NFILT. This process then proceeds in moving arc fashion along the entire data array. The convolutions at the endpoints are accounted for by reflection of the data at the endpoints. See the listing in Appendix C for more details.

4.2.4. Subroutine CONVT

This subroutine converts the displacement data from counts to voltages and then to engineering units (microns, in this case). The conversion is nonlinear as discussed previously in Section 2 and as expressed in Eq. (2.1). The data are also converted from microns to centimeters to conform with other test data.

4.2.5. Subroutine DATAIN

This subroutine inputs the data from a previously generated file into a dummy array. Under the control of subroutine ORIENT, the data are then transferred into the appropriate 3-dimensional array.

4.2.6. Subroutine DIFFER

This subroutine provides the control for the calculation of the first and second derivatives. The order of processing is:

- Displacement is inputted,
- Velocity is generated using an FIR differentiator,
- Velocity is smoothed using an FIR lowpass filter,
- Acceleration is generated using an FIR differentiator, and
Acceleration is smoothed using an FIR lowpass filter.

4.2.7. Subroutine DISS4

This subroutine generates the plot, using DISSPLA (Version 8.2), and stores it on a file named PLFILE. This plot file can then be viewed and printed at the computer terminal and/or sent to the CALCOMP plotter.

4.2.8. Subroutine FILT

This subroutine inputs the FIR coefficients and convolutes the data under the control of the variable ITYPE. If ITYPE=1, the data are lowpass or highpass filtered; if ITYPE=2, the data are differentiated. Note that the processed data are returned in the same array in which they were inputted.

4.2.9. Subroutine ORIENT

This subroutine inputs the data related control parameters, reads NCH sets of data into the appropriate part of the 3-dimensional array DAT, converts the data into engineering units if ICVT ≠ 0, and lowpass filters the data if IFILT ≠ 0. If IDERIV = 1, displacement data are inputted and the velocities and accelerations are calculated; if IDERIV = 0, all three are inputted. For each data set, the parameters MIN, NIN, and IU are read in. MIN and NIN are indices which control the placement of the data set into the three-dimensional array, as in DAT(MIN,NIN,L), and IU indicates on which tape unit the data file resides.

4.2.10. Subroutine PLOT4

This subroutine provides the control over what is plotted by subroutine DISS4. Also, the data must be put into 1-dimensional arrays to be plotted.

4.2.11. Subroutine WRDAT

This subroutine writes all the data that have been processed onto a file on tape unit 18. This file is then saved and used as an input to the second program.

4.3. Computer Program MUPRED

The flowchart for MUPRED is shown in Figure 4.2. The main program inputs the control variables and then calls the subroutines. The control variables are: NCH which is the number of channels to be inputted (usually 6), NPLOTP, NPLOTC and NPLOTU which contain the number of plots to be generated in subroutines PREDCT, CALCZ, and UNITV, respectively, and IPRINT which controls the writing of an output data file. A few other data related variables are inputted: LKEY, in particular, which is defined as the index in the input data array that corresponds to the time when the midpoint of the rotating band of the projectile passes sensor 1. When plots are generated, time is zeroed at the time of LKEY.
Figure 4.2. Flowchart For Program MUZPRED

4.3.1. Subroutine CALCZ

The data base [5][6] on which the development of this analysis program relied did not contain muzzle recoil motion. Hence, the axial muzzle motion analysis based on the procedure outlined in Eqs. (3.10) to (3.12) was not incorporated into the computer programs. However, since this motion was obtained by an earlier experiment using the same gun fixture, projectile type and propellant charge, a provision has been added to this subroutine to scale an externally supplied function for the muzzle recoil velocity to the projectile in-bore travel and gas pressure history. This function, a 5-th order polynomial, was generated by least squares model fitting of the average of three data sets. Its coefficients are read into array C. The times of beginning of recoil motion, LZM, maximum pressure, LPM, and shot exit, LEM, of this model function are inputted as well as the corresponding last two of the data set, LPD and LED. After proportionally scaling LZD, the scaled time

*) Axial muzzle displacement data recorded about four calibers back of muzzle face with a two-dimensional displacement transducer (ZIMMER) were gracefully supplied to BRL by Mr. T.O. Andrews, Royal Armament Research and Development Establishment, Fort Halstead, Kent, UK, March 1985.
series for the muzzle recoil velocity is computed by assigning the value zero to all time points when \( J_l < LZD \) and the value of \( LED \) to all time points when \( J_l > LED \). The displacement array is then obtained by numerical integration of the velocity over time.

The distances of the sensors from the muzzle are read into a 3x2 array \( Z \) along with the reference distance \( Z_{REF} \). At each point in time a least squares fourth-degree polynomial, with the second- and third-degree coefficients set equal to zero, was fit to the data of all three sensors according to Eqs. (3.4) through (3.9). The horizontal and vertical fits are done separately and the results of each fit are evaluated at \( Z_{REF} \) and saved in array \( DAT \).

At this point the information in array \( DAT \) is:

\[
\begin{align*}
\text{DAT(1,1,L)} & : \text{COEF(3) - horizontal}, \\
\text{DAT(1,2,L)} & : \text{COEF(3) - vertical}, \\
\text{DAT(2,1,L)} & : \text{displacement at } Z_{REF} \text{ - horizontal},
\text{DAT(2,2,L)} & : \text{displacement at } Z_{REF} \text{ - vertical},
\text{DAT(3,1,L)} & : \text{slope at } Z_{REF} \text{ - horizontal},
\text{DAT(3,2,L)} & : \text{slope at } Z_{REF} \text{ - vertical},
\text{DAT(4,1,L)} & : \text{COEF(1) - horizontal},
\text{DAT(4,2,L)} & : \text{COEF(1) - vertical},
\text{DAT(5,1,L)} & : \text{COEF(2) - horizontal},
\text{DAT(5,2,L)} & : \text{COEF(2) - vertical},
\text{DAT(6,1,L)} & : \text{recoil velocity}, \text{ and}
\text{DAT(6,2,L)} & : \text{recoil displacement}.
\end{align*}
\]

Next, subroutine UNITV is called to calculate the unit vector at each discrete time, using the slopes. That procedure is described in Section 4.3.11. During this procedure, the arrays \( \text{DAT(6,1,L)} \) and \( \text{DAT(6,2,L)} \) are overwritten.

The displacement at \( Z_{REF} \) is then differentiated to form the velocity, lowpass filtered and saved also in array \( DAT \), overwriting \( \text{DAT(3,1,L)} \) and \( \text{DAT(3,2,L)} \). At this point the information in array \( DAT \) is:

\[
\begin{align*}
\text{DAT(1,1,L)} & : \text{COEF(3) - horizontal}, \\
\text{DAT(1,2,L)} & : \text{COEF(3) - vertical}, \\
\text{DAT(2,1,L)} & : \text{displacement at } Z_{REF} \text{ - horizontal},
\text{DAT(2,2,L)} & : \text{displacement at } Z_{REF} \text{ - vertical},
\end{align*}
\]
DAT(3,1,L) velocity at ZREF - horizontal,
DAT(3,2,L) velocity at ZREF - vertical,
DAT(4,1,L) COEF(1) - horizontal,
DAT(4,2,L) COEF(1) - vertical,
DAT(5,1,L) COEF(2) - horizontal,
DAT(5,2,L) COEF(2) - vertical,
DAT(6,1,L) $e_{31}^t$, and
DAT(6,2,L) $e_{32}^t$.

The plots are then generated as specified by NPLOTC and the arrays MDAT and NDAT. Any inputs required for plotting reside on a file on tape unit 7.

4.3.2. Subroutine COEF1

This subroutine inputs the coefficient array and other necessary parameters of a previously generated FIR lowpass or highpass filter.

4.3.3. Subroutine COEF2

This subroutine inputs the coefficient array and other necessary parameters of a previously generated FIR differentiator.

4.3.4. Subroutine CONVOL

This subroutine does a linear convolution of the NFILT coefficients with a data array of length NFILT. This process then proceeds in moving arc fashion along the entire data array. The convolution at the endpoints are accounted for by reflection of the data at the endpoints. See the listing in Appendix C for more details.

4.3.5. Subroutine DATAIN

This subroutine inputs the data from program MUZM040 into a three-dimensional array as specified by variables M and N. The input data array dimension is 4100, but, because of central memory size limitations, the data-processing array DAT is restricted to 2500 points.

4.3.6. Subroutine DATA4

This subroutine prepares the data arrays for plotting. Special provision is made to zero the data at the time LKEY mentioned in the main program; the abscissa is zeroed on the time plots and both abscissa and ordinate on the x-y plots.
4.3.7. Subroutine DIFFER

This subroutine calls the subroutines required for differentiating if IUD ≠ 0 and then calls the ones required for lowpass or highpass filtering if IUUF ≠ 0.

4.3.8. Subroutine DISS4

This subroutine generates the plot, using DISSPLA (Version 9.0), and stores it on a local file named META. Up to three curves can be plotted and options are available for color, scales and labels. For more details see the subroutine listing.

4.3.9. Subroutine FILT

This subroutine reads in the FIR lowpass or highpass filter coefficients and calls the subroutine CONVOL to convolute the data. Note that the processed data are returned in the same array in which they were inputted.

4.3.10. Subroutine PREDCT

This subroutine does a straight line extrapolation from the data of sensors 2 and 3 to the position of sensor 1, the variables DZ31 and DZ32 being the distances from sensor 3 to sensor 1 and 2, respectively. The values of the prediction can then be compared with the ones of sensor 1; the magnitudes and phase angles of both data sets are calculated to aid in this comparison.

In the vicinity of LKEY the displacements are averaged over short time spans and their magnitudes and phase angles are calculated, stored, and printed.

At this point the information in array DAT is:

DAT(1,1,L) sensor 1 displacement - horizontal,
DAT(1,2,L) sensor 1 displacement - vertical,
DAT(2,1,L) sensor 2 displacement - horizontal,
DAT(2,2,L) sensor 2 displacement - vertical,
DAT(3,1,L) sensor 3 displacement - horizontal,
DAT(3,2,L) sensor 3 displacement - vertical,
DAT(4,1,L) prediction displacement - horizontal,
DAT(4,2,L) prediction displacement - vertical,
DAT(5,1,L) prediction magnitude,
DAT(5,2,L) prediction phase angle, degrees,
DATA(6,1,L) sensor 1 magnitude, and
DATA(6,2,L) sensor 1 phase angle, degrees.

NPLOT plots are then generated with the input arrays MDAT and NDAT
controlling what is plotted. Any inputs required for plotting reside on a
file on tape unit 3.

4.3.11. Subroutine UNITV

This subroutine calculates the translation and rotation
parameters as described in Section 3.2.3, Eq. (3.16) in particular. The
three-dimensional array DATA, at entry to the subroutine, contains the
information as shown in subroutine CALCZ. The array is overwritten again in
this subroutine as follows:

\[
\begin{align*}
\text{DATA}(1,1,L) &= e'_{j3}, j = 1, 2, \text{ or } 3, \\
\text{DATA}(1,2,L) &= \text{(irrelevant)}, \\
\text{DATA}(2,1,L) &= \text{(irrelevant)}, \\
\text{DATA}(2,2,L) &= \text{(irrelevant)}, \\
\text{DATA}(3,1,L) &= \text{slope at ZREF-horizontal}, \\
\text{DATA}(3,2,L) &= \text{slope at ZREF-vertical}, \\
\text{DATA}(4,1,L) &= \text{(irrelevant)}, \\
\text{DATA}(4,2,L) &= \text{(irrelevant)}, \\
\text{DATA}(5,1,L) &= \text{(irrelevant)}, \\
\text{DATA}(5,2,L) &= \text{(irrelevant)}, \\
\text{DATA}(6,1,L) &= e'_{j1}, j = 1, 2, \text{ or } 3, \text{ and} \\
\text{DATA}(6,2,L) &= e'_{j2}, j = 1, 2, \text{ or } 3.
\end{align*}
\]

NPLOTU plots are then generated as specified by the input arrays MDAT and
NDAT. Any inputs required for plotting reside on a file on tape unit 10.

4.3.12. Subroutine WRFILE

This subroutine takes data from a three-dimensional array and
transfers all or part of one column into a one-dimensional array which is then
written on an output file located on tape unit 9. This procedure is done NARR
times and the columns to be written are chosen according to the input arrays
MDAT and NDAT. LST and LSP are the starting and stopping indices,
respectively, of the data to be written.
5. CONCLUSIONS

The methodology described in the report allows the exploitation of the SDT technology for the determination of the muzzle motion during the in-bore and launch motion of the projectile with a very high accuracy. The theoretical foundation is general. It contains all the equations and procedures necessary for the analysis of three-dimensional time series presenting the tube displacement in the longitudinal as well as in the horizontal and vertical directions from SDT type instrumentation at \( k \)-locations. This allows the determination of five of the six degrees-of-freedom parameters as a function of time for all points lying on the tube axis in the spatial measurement domain. Only the rotation about the longitudinal tube axis is not obtainable. For most gun accuracy related investigations however, the knowledge of this parameter is not required, since one is mainly interested in the transverse velocity and the aiming direction of the muzzle and in their temporal derivatives during shot exit.

Currently the computer program is explicitly set up for the analysis of transverse data collected at three locations at the muzzle end of the tube while allowing for the muzzle recoil. It can easily be extended, if necessary, to \( n > 3 \) locations and to include determination of the axial muzzle motion from respective SDT data, employing the outlined theoretical formulation.
REFERENCES


REFERENCES (continued)


A-6 Biele, J.K., Lateral Motion of a 105mm Smoothbore Tank Cannon, Workshop on Projectile Gun Dynamics under the Auspices of DEA-G-1060, USA Ballistic Research Laboratory, Aberdeen Proving Ground, MD, April 1979.


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APPENDIX A

BRIEF REVIEW OF CANNON MOTION MEASUREMENT TECHNIQUES
APPENDIX A

BRIEF REVIEW OF CANNON MOTION MEASUREMENT TECHNIQUES

A.1 Introduction

Various instrumentation and measurement techniques are available to monitor the gun tube motion during the in-bore travel and launch of a projectile. Most methods are based on the utilization of streak photography, electrooptical displacement transducers, optical levers, electromagnetic proximity transducers, interferometry, electromechanical devices, strain gauges, accelerometers, etc. The authors, not being aware of any publication containing a review of experimental methods for measuring tube motion, felt compelled for reasons of completeness to provide a very brief description of the above mentioned methods with some references to applications.

A.2. Streak Photography

Streak photography [A-1] is probably one of the best photographic techniques for recording the motion history of a vibrating tube. In this instrumentation, the image formed by a small reflector bonded to the surface is recorded on film by a moving-film, shutterless camera in the form of a continuous, wavy line against a contrasting background. This time-displacement record can be evaluated with an accuracy of the order of $10^{-3}$ cm and a time resolution of about 1 msec. Due to the extra labor and time involved in processing the optical data this technique is relatively costly over techniques which utilize electronic recording.

A.3. Electrooptical Displacement Transducers

Electrooptical displacement transducer instrumentation combines the advantage of optics and electronic recording by incorporating an optical system in an electronic circuit. Two different arrangements are described here.

The first one employs a light-dark discontinuity on the cannon surface which is imaged by a lens system onto a photocathode which converts the optical image into an electron beam. This beam, in turn, is imaged via an electromagnetic field onto the center of a small aperture and thereafter amplified by an electron multiplier. The resulting current is used as a servo loop control for the electromagnetic field generator. The correcting current, necessary to keep the electron image centered on the aperture, is recorded as a measure of target deflection. Displacement range and resolution are a function of the focal length of the lens system and its distance from the target. In the US, one-dimensional electrooptical transducers manufactured by Optron, a Division of Universal Technology Inc., of Woodbridge, Connecticut have been successfully employed for measuring gun dynamics [A-2][A-3][A-4]. In Western Europe two-dimensional electrooptical transducers manufactured by Zimmer OHG, Darmstadt, FRG, are employed for the same purpose [A-5][A-6][A-7] and as a standard for calibrating other less expensive instrumentation for measuring tube motion.

In the second arrangement, a collimated light beam passes over a knife edge and partially illuminates a large area light-sensitive photodiode through
a narrow slit. The knife edge, e.g., a razor blade, is mounted to the gun tube, parallel to the tube axis and perpendicular to the light beam, and is positioned such that it partially blocks the light beam passing through the slit. For instance, if the knife edge is arranged horizontally in the vertical plane of the tube axis, any vertical tube motion will move the edge up or down and regulate the light striking the sensor. The detected signal is then amplified and recorded. The signal change is directly proportional to the gun tube displacement in the vertical direction. By using two light sources and corresponding sensors positioned orthogonally, both the horizontal and vertical components of the tube motion can be measured [A-8][A-9].

A.4. Optical Lever Instrumentation

Optical lever instrumentation is ideally suited for monitoring local angular deflection of gun tubes [A-10]. It has recently been integrated with electronic recording [A-11] and applied to the measurement of the muzzle-pointing direction [A-12][A-13][A-14]. In this measurement technique a collimated light beam is incident on and reflected by a mirror rigidly attached to the gun tube and imaged via a lens system onto a two-dimensional, position-sensing photodetector. As the gun tube changes its curvature, the mirror rotates with it, thereby changing the direction of the reflected light beam and, thus, the location of the light spot on the photodetector. The x and y components of the induced photocurrent are recorded as a function of time and converted into a displacement history with respect to the electric center of the sensor. Superposition of the geometry of the optical lever setup yields the local angular deflection history. This type of instrumentation is employed in muzzle reference systems for tank guns.

A.5. Electromagnetic Proximity Transducers

Electromagnetic proximity transducers are increasingly being used for measuring tube displacements [A-15][A-16][A-17]. Most operate on the eddy current principle: a varying electromagnetic field, usually in the radio frequency range, is generated by an oscillator and radiated from its active inductance coil/antenna to a proximate surface location or protrusion of the tube. Eddy currents are induced in the metallic surface and generate an electromagnetic field which then couples back into the active inductance coil. As the surface vibrates, the recoupling to the inductance coil changes, which, in turn, causes a change in the oscillator impedance and, thus, a modulation in the oscillator current frequency and/or current amplitude. This modulation is recorded as a function of time and transferred into a displacement history. Inductive proximity probes which can readily be adapted to the measurement of gun dynamics are commercially available.

The Schmidt displacement transducer (SDT) described in this report is a proximity transducer, which integrates over the tube perimeter, thus suppressing contributions from local vibrations and yielding a large signal-to-noise ratio.

A.6. Interferometric Measurement Techniques

Interferometric measurement using laser as well as microwave techniques can also be used to record certain dynamic parameters of tube motion. In this technique a monochromatic coherent electromagnetic wave is divided by a beam
splitter into two parts which travel different paths and recombine to form interference fringes. If one of the beams is reflected by a moving object, which in our case is the tube surface, well-defined maxima and minima in the fringe intensity are produced and recorded either photographically or electrically. MW interferometry represents a convenient tool to monitor the axial recoil motion history of guns at the breech as well as at the muzzle. Using an appropriate experimental setup, the latter event can even be obtained together with projectile travel from in-bore MW interferometry [A-18]. In the visible spectrum, D. Warken [A-19][A-20] pioneered the application of holographic interferometry and laser speckle photography for the investigation of the spatial displacement field of local tube surfaces in clearly defined time intervals. Though the experimental arrangement for providing a time sequence of holograms or speckle photographs may be quite cumbersome to set up and the recorded information difficult to analyze, these optical methods are well suited for the detailed investigation of the displacement field of those locations on the gun surface which have inhomogeneities in geometry or in material properties. For typical gun tube vibration measurements however, they are too complex and too detailed. On the contrary, laser interferometry with electronic recording is very attractive for the temporal measurement of local tube motion. A multitude of interferometer configurations have been developed to meet numerous experimental requirements. Three of them, generally identified by the acronyms DISAR [A-21], VISAR [A-22] and TRANSAR [A-23], should easily be adaptable for the measurement of gun motion [A-24]. The first is basically a Michelson interferometer in which the light source is a high-powered laser and the target a diffuse scatterer. The backscattered light is collected by a telescope and brought to interference with the unscattered reference beam. In the second configuration, essentially a laser Doppler velocimeter, the backscattered light is again collected and collimated by a lens system and is divided into two beams. After sending one beam around an optical delay leg it is recombined with the undelayed beam. The interference fringe history thus formed is proportional to the velocity change of the reflecting surface. In the third configuration, the TRANSAR, the backscattered light is collected at two different directions, usually in a diagonally opposite setup, via telescopes and optically heterodyned to yield the temporal displacement/velocity of the scattering surface location orthogonal to the direction of the incident beam and in the plane formed by the direction in which the scattering is observed.

A.7. Electromechanical Devices

A recent innovation of an electromechanical device is the "tuning fork" transducer developed by S&D Dynamics [A-25]. In this measurement technique, a cylindrical section of the cannon is sandwiched between two prongs of a tuning fork-like mechanical device with its stem rigidly attached to a nonmovable mass. As the tube moves towards one of the prongs, it forces the prongs to move with it, which, in turn, causes a bending of the stem. This deformation is then picked up by strain gauges mounted on the stem and recorded.

A.8. Strain Gauge Instrumentation

Strain gauge instrumentation usually employs a matrix of temperature-compensating strain transducers appropriately aligned and mounted on the outer surface of the cannon to measure local tube strains [A-6][A-26]. Each strain gauge forms an active leg in a Wheatstone bridge. The strain contribution to
tube bending, however, must be separated analytically from that produced by the gas pressure, the gun recoil, and the dynamic contact of the projectile with the bore surface during projectile in-bore travel and launch, before it can be translated into tube curvature.

A.9. Accelerometer Instrumentation

The accelerometer instrumentation as customarily employed [A-17][A-26][A-27][A-28] uses piezoelectric accelerometers which are bonded to the outer surface of the cannon in a matrix arrangement to record local tube accelerations. Because of the unfortunate susceptibility of piezoelectric transducers to high frequency shocks which can produce temporary step function like zero shifts in the signals, their application for monitoring cannon vibration is limited.
APPENDIX B

ESTABLISHMENT OF CANNON FLEXURE WITH RESPECT TO BORE SIGHT REFERENCE LINE PRIOR TO SHOT START
ESTABLISHMENT OF CANNON FLEXURE WITH RESPECT TO BORE SIGHT REFERENCE LINE PRIOR TO SHOT START

There are a few gun-related observables which should or must be determined just prior to the commencement of fire. They represent the initial values of gun flexure and aiming point. If their determination is simultaneously done with the measurement of the tube displacements, we can establish a frame of reference where these three sets of observables are correlated. Hence, it is presumed that a muzzle/tube displacement measurement arrangement as described in Section 3.1 is an integral part of the overall measurement setup and is used to monitor the tube flexure during the establishment of the aiming point and the initial tube curvature.

B.1. Gun Aiming Point/System Frame Of Reference

In many gun accuracy-related investigations, we are interested in the relationship between the projectile impact and the initial aiming point of the gun. Restricting the discussion to direct fire weapons, we can employ a boresight or an alignment telescope for the establishment of the aiming point or points on the target. Because of the simplicity of the measurement, the intersection of the line of sight given by a boresight placed into the muzzle or breech section of the cannon with the target witness board is habitually used as the reference point. However, any other section of the bore may be used for establishing the line of aim. For example, the line of sight which passes through the center of the breech and the center of the muzzle is also employed as a line of aim as reference.

In the following we assume that the line of aim is established by a boresight placed into the muzzle and presents the mean of many measurements in which the boresight has systematically been rotated and, if necessary, reseated. By statistically averaging the observations, we can practically eliminate gun locality and human related bias. At the same time the aiming points are recorded, we may also record the muzzle displacements and calculate from their averages the location and the slope of the muzzle. These expressions are respectively,

\[ S_A(\nu) = S(\nu, z=0, \lambda), \nu=1,2 \text{ and } \hat{e}_i^{\nu} = \hat{e}_i^{\nu}(\lambda), i=1,2,3, \] (B.1)

using the algorithm described in Section 3.2. Because of the free beam condition at the muzzle face, the muzzle end is basically a rigid hollow cylinder. This allows us to postulate a frame of reference which has its origin at \((S_A(1), S_A(2), 0)\) and its third axis pointed to the aim point. It has to be noted that this line of aim is not the actual one at shot start, since it has been established with the additional weight of the boresight in the muzzle. If the boresight is removed, the tube flexure will readjust itself to a new slightly different stress equilibrium, thereby changing its muzzle shape. However, with the system frame of reference defined, any change in the muzzle motion can be expressed relative to it.
B.2. Bore Straightness/Axis

Generally, gun tubes are not straight. Reasons for this include residual stresses, variation in wall thickness, machining accuracy and tolerances, eccentricity of rifling, storage position, environment, etc. Also large thermal distortion can be induced by solar irradiation. The sun-exposed side of the cannon will warm up and expand with respect to the shadowed part. This produces, in addition to the natural crookedness and the gravitational droop, a curvature in the cannon with its center of curvature lying in the shadowed plane, thus bending the muzzle away from the sun. Hence, it is important to measure the initial conditions of the tube bending immediately prior to the commencement of fire for gun accuracy, diagnostic, and model simulation purposes.

Up till now tube straightness or bend has been measured with an alignment telescope and an illuminated bull's-eye target which is moved through the tube [B-1]. The telescope is placed on an adjustable mount near the muzzle or breech of the tube and adjusted so that the line of sight passes through the center of the bore at the commencement of the rifling or forcing cone and the muzzle. The deviations from the line of sight are measured at various positions along the tube axis in both horizontal and vertical directions with an accuracy of about 0.025mm by means of micrometer attachments on the telescope. This cumbersome optical measurement technique is amenable to automatization by introducing a laser beam as line of reference, replacing the bull's eye target by a two-dimensional electrooptical position sensor, mechanizing the push or pull of the target carriage through the bore, and digitally recording the beam location as a function of the axial displacement of the target. Such a device has recently been introduced by Watervliet Arsenal to measure the tube curvature during and after manufacturing. The target carriage is centered in the bore by mechanical springs which limits the accuracy of the measurement. Because gun dynamics model simulations strongly indicate that muzzle motion at shot exit is very sensitive to the tube bend at shot start, the inaccuracy introduced by the mechanical alignment mechanism of the target carriage with the bore center must be reduced as much as possible.

For smoothbore guns, this can be done with relative ease by mounting a SDT system into the outer surface of the probe concentric and coplanar with the photodiode and recording the respective signals concurrently as a function of the axial displacement. The SDT instrumentation provides the location of the geometric center of the bore relative to the probe center and the position sensor gives the location of the reference laser beams with respect to the probe center. By introducing a parallel plate which is mounted on a motor-driven, computer-controlled goniometric cradle or rotational displacement device into the light path, we can displace the light beam in the plane of rotation in a controlled way. By letting the parallel plate oscillate about its zero position normal to the beam and recording the beam location at the zero transition and the extreme displacements, we even can account for any rotational movement of the probe about the axis and uniquely correlate the bore axis relative to the reference coordinate system given by the laser beam arrangement (Figure B.1). This measurement will yield the geometric center of the bore, \( \sigma \), with regard to the reference beam and as a function of the axial position \( \zeta \):
\[ \dot{\sigma}(\zeta) = (\xi, \eta, \zeta) \] \hspace{1cm} \text{(B.2)}

2-D PHOTODIODE  
SDT  
TUBE  
PROBE  
BEAM

PARALLEL PLATE MOUNTED ON A ROTATIONAL DISPLACEMENT DEVICE

Figure B.1. Accurate Measurement Of Bore Curvature Prior To Shot Start

Measuring the tube flexure at the same time yields

\[ S^*(v, z, \zeta), \quad v=1,2, \] \hspace{1cm} \text{(B.3)}

where \( z \) and \( \zeta \) are the locations of the SDT instrumentation and the probe, respectively. We can calibrate the tube axis as defined by the individual SDT measurements to the bore axis as

\[ S^*(v, z, \zeta) = S^*(v, z, \zeta) - [S^*(v, z, z) - \sigma_v(z)], \quad v=1,2. \] \hspace{1cm} \text{(B.4)}

If we align the laser reference beam collinear with the line of aim we can avoid minute translation and rotation in correlating the two reference systems and can define the alignment function \( S_o(v, \mu) \) appearing in Eq. (3.2) as

\[ S_o(v, \mu) = S^*(v, z_{\mu}, z_{\mu}) - \sigma_v(z_{\mu}), \quad v=1,2, \quad \mu=1,2, \ldots m. \] \hspace{1cm} \text{(B.5)}
APPENDIX C

COMPUTER PROGRAMS
C.1. Program MUZMO40

C.1.1. Listing Of Job Control Language Of MFA File MUZMO40/UN=BOOTS

BOOTS, STMFZ, P5, T50, MS300000.
ACCOUNT, PDXXX.
REQUEST, PLFILE, *PF.
REQUEST, TAPE7, *PF.
REQUEST, TAPE18, *PF.
ATTACH, DISSPLA, ID=DISSPLA.
ATTACH, COMPRES, ID=DISSPLA.
LIBRARY, *, DISSPLA, COMPRES.
FTN, LCM=1, L=0.
BEGIN, GETMFAU, FILE, LF=TAPE1, PF=BR0512A, UN=BOOTS.
BEGIN, GETMFAU, FILE, LF=TAPE2, PF=BR0511A, UN=BOOTS.
BEGIN, GETMFAU, FILE, LF=TAPE8, PF=BR0509A, UN=BOOTS.
BEGIN, GETMFAU, FILE, LF=TAPE9, PF=BR0508A, UN=BOOTS.
BEGIN, GETMFAU, FILE, LF=TAPE10, PF=BR0510A, UN=BOOTS.
BEGIN, GETMFAU, FILE, LF=TAPE11, PF=BR0507A, UN=BOOTS.
BEGIN, GETMFAU, FILE, LF=TAPE4, PF=DIFF1, UN=BOOTS.
BEGIN, GETMFAU, FILE, LF=TAPE17, PF=LPF62, UN=BOOTS.
MAP, OFF.
LGO.
BEGIN, SAVMFAU, FILE, LF=TAPE18, PF=DVA05U, UN=BOOTS.
APPENDIX C

C.1.2. Listing Of FORTRAN Program

1  PROGRAM MUZZLECINPUT, OUTPUT, TAPF5=INPUT, TAPF6=OUTPUT, TAPE1, TAPE17
   *
C   ANALYSIS OF MUZZLE MOTION DATA - PROGRAM 1
C
5  COMMON/L/MIN(6), NIN(6), NTS(24), NCH, IDERIV, IFILT, NPT, LDEL
      *
      , NLS0, LABEL(10), LABL(3, 2, 24), LCNT(2, 7)
      REAL LDEL
      COMMON DUM(1),
10  * X(5000), Y1(5000), Y2(5000), Y3(5000), Y4(5000), Y5(5000), Y6(5000)
      COMMON/LEV1/ DTIME, CT(3, 2), CT1(3, 2), CT2(3, 2), CT3(3, 2), CVT(3, 6)
      *
      , TSTART, ZZ(3, 2)
      COMMON/LEV2C/DAT(3, 2, 5000), DATD(3, 2, 5000), DATDD(3, 2, 5000)
      LEVEL 2, DAT, DATD, DATDD
15  LABEL(1)=10H BOOTS
      LABEL(2)=10H BLDG. 390
      LABEL(3)=10H X 6121
      LABEL(4)=10HMUZZLE
      CALL COMPRS
20  CALL SETDEV(0, 6)
      READ(5, 2) IPLT1, IPLT2, IPLT3, IPRT
      WRITE(6, 1) IPLT1, IPLT2, IPLT3, IPRT
      CALL ORIENT
      IF(IPLT1.EQ.1) CALL PLOT4(DAT)
25  IF(IDERIV.EQ.0) GO TO 100
      CALL DIFFER
      IF(IPLT2.EQ.1) CALL PLOT4(DATD)
      IF(IPLT3.EQ.1) CALL PLOT4(DATDD)
100  IF(IPRT.EQ.1) CALL WRDAT
30  CALL DONEPL
      STOP
      1  FORMAT(1H1, ' IPLT1 =', I3, ' IPLT2 =', I3, ' IPLT3 =', I3, ' IPRT =', I3)
      2  FORMAT(10I3)
      END
SUBROUTINE COEF1(NFILT,H,IU)
C
C READS IN COEFFICIENTS OF AN FIR LOWPASS OR HIGHPASS FILTER
C
5 DIMENSION H(512)
READ(IU)NFILT,FP,TBWID,DP,DS
IF(ISW.NE.1)WRITE(6,1)
IF(ISW.NE.1)WRITE(6,2)NFILT,FP,TBWID,DP,DS
N=(NFILT+1)/2
READ(IU)H(I),I=1,N
IF(ISW.NE.1)WRITE(6,3)
IF(ISW.EQ.1)GO TO 200
DO 100 I=1,N,5
IST=I+4
15 IF(IST.GT.N)IST=N
WRITE(6,4)I,(H(II),II=I,IST)
100 CONTINUE
WRITE(6,5)
200 ISW=1
RETURN
1 FORMAT(//,' FILTER PARAMETERS,')
2 FORMAT(5X,' NFILT = ',I5,' FP = ',F10.5,' TBWID = ',F10.5,
     * ' DP = ',F10.5,' DS = ',F10.5)
3 FORMAT(5X,' FILTER COEFFICIENTS')
25 FORMAT(5X,I5,5E15.8)
5 FORMAT(//)
END
SUBROUTINE COEF2(NFILT,H,IU,JTYPE)

READ IN COEFFICIENTS OF AN FIR DIFFERENTIATOR

DIMENSION H(64),EDGE(20),FX(10),WTX(10)

IF(ISW.NE.1)WRITE(6,1)
READ(IU)NFILT,JTYPE,NBANDS
IF(ISW.NE.1)WRITE(6,2)NFILT,JTYPE,NBANDS
JB=2*NBANDS
READ(IU)(EDGE(J),J=1,JB)
IF(ISW.NE.1)WRITE(6,5)(EDGE(J),J=1,JB)
READ(IU)(FX(J),J=1,NBANDS)
IF(ISW.NE.1)WRITE(6,6)(FX(J),J=1,NBANDS)
READ(IU)(WTX(J),J=1,NBANDS)
IF(ISW.NE.1)WRITE(6,7)(WTX(J),J=1,NBANDS)
READ(IU)(H(J),J=1,64)
IF(ISW.NE.1)WRITE(6,3)
IF(ISW.EQ.1)GO TO 200

N=NFILT/2+1
DO 100 I=1,N,5
IST=I+4
IF(IST.GT.N)IST=N
WRITE(6,4)I,(H(II),II=I,IST)
100 CONTINUE

WRITE(6,8)

200 ISW=1
RETURN

1 FORMAT('//,' FILTER PARAMETERS')
2 FORMAT(5X,' NFILT = ',I5,' JTYPE = ',I5,' NBANDS = ',I5)
3 FORMAT(5X,' FILTER COEFFICIENTS')
4 FORMAT(5X,I5,5E15.8)
5 FORMAT(5X,' EDGE ',20F6.4)
6 FORMAT(5X,' FX ',10F6.2)
7 FORMAT(5X,' WTX ',10F7.1)
8 FORMAT('//')
END
SUBROUTINE CONVOL(H,X,NDIM,NFILT,JTYPE)

THIS CONVOLUTION IS VALID ONLY FOR NFILT = ODD INTEGER
NFILT MAX. SET TO 1023 - CAN BE RESET BE REDIMENSIONING ARRAYS

IF JTYPE = 1, EVEN SYMMETRY ASSUMED FOR REFLECTION AT ENDPOINTS
IF JTYPE = 2, ODD SYMMETRY ASSUMED FOR REFLECTION AT ENDPOINTS

DIMENSION H(512),X(NDIM),S(1030),T(1030)

IF(JTYPE.EQ.1)SGN=1.
IF(JTYPE.EQ.2)SGN=-1.
IF(JTYPE.EQ.1)A=0.
IF(JTYPE.EQ.2)A=2.
IF(JTYPE.LT.1.OR.JTYPE.GT.2)WRITE(6,1)
IF(JTYPE.LT.1.OR.JTYPE.GT.2)STOP

L=NFILT-1
NCOEF=NFILT/2+1
J=NCOEF
K=J-1
DO 10 I=1,NCOEF
  S(I)=SGN*X(NCOEF-I+1)+A*X(1)
  S(NFILT-I+1)=X(J)
  T(NCOEF+I-1)=SGN*X(NDIM-I+1)+A*X(NDIM)
  J=J-1
10 CONTINUE

DO 40 I=1,NDIM
  X(I)=.0
  DO 20 J=1,K
    X(I)=X(I)+H(J)*(SGN*S(J)+S(NFILT-J+1))
20 CONTINUE

  X(I)=X(I)+H(NCOEF)*S(NCOEF)
  IF(I.EQ.NDIM)GO TO 50
  DO 30 J=1,L
    S(J)=S(J+1)
30 CONTINUE

  S(J)=S(J+1)
35 CONTINUE

  IF(I.LE.NDIM-NCOEF)S(NFILT)=X(I+NCOEF)
  IF(I.GT.NDIM-NCOEF)S(NFILT)=T(I+NFILT-NDIM+1)
40 CONTINUE

RETURN

1 FORMAT(' ERROR IN SUB CONVOL - JTYPE NOT EQUAL TO 1 OR 2')
END
SUBROUTINE CONVT(M,N,ISW)

CONVERSION OF DATA (IN COUNTS) TO DISPLACEMENTS

COMMON/I/MIN(6),NIN(6),NTS(24),NCH,IDERIV,IFILT,NPT,LDEL
* ,NLSQ,LABEL(10),LABL(3,2,24),LCNT(2,7)
REAL LDEL
COMMON/LEV1/DTIME,CT(3,2),CT1(3,2),CT2(3,2),CT3(3,2),CVT(3,6)
* ,TSTART,ZZ(3,2)
COMMON/LEV2C/DAT(3,2,5000),DATD(3,2,5000),DATDD(3,2,5000)
LEVEL 2,DAT,DATD,DATDD
ISW=ISW+1
J=N
IF(M.EQ.1.AND.N.EQ.2)J=4
WRITE(6,1)M,N,CT(M,N),CVT(M,J)
DO 100 L=1,NPT
DAT(M,N,L)=DAT(M,N,L)*CT(M,N)
IF(M.EQ.1)GO TO 100
DAT(M,N,L)=DAT(M,N,L)*CVT(M,N)
100 CONTINUE

CHANGE MICRONS TO CENTIMETERS
DO 150 L=1,NPT
DAT(M,N,L)=DAT(M,N,L)*1.E-4
150 CONTINUE

IF(M.GT.1)GO TO 300
IF(MOD(ISW,2).NE.0)GO TO 300
DO 200 L=1,NPT
SQ1=SQRT(1.+CVT(1,2)*DAT(M,1,L)**2+CVT(1,3)*DAT(M,2,L)**2)
SQ2=SQRT(1.+CVT(1,5)*DAT(M,1,L)**2+CVT(1,6)*DAT(M,2,L)**2)
DAT(M,1,L)=CVT(1,1)*DAT(M,1,L)/SQ1
DAT(M,2,L)=CVT(1,4)*DAT(M,2,L)/SQ2
200 CONTINUE
300 RETURN
1 FORMAT(2I3,2F10.5)
END
SUBROUTINE DATAIN(M,N,Z,IU)

INPUT EXPERIMENTAL DATA

COMMON/I/MIN(6),MIN(6),NTS(24),NCH,IDERIV,IFILT,NPT,LDEL
* NLSQ,LABEL(10),LABL(3,2,24),LCNT(2,7)
REAL LDEL
COMMON/LEV/DTIME,CT(3,2),CT1(3,2),CT2(3,2),CT3(3,2),CVT(3,6)
* TSTART,Z(3,2)
DIMENSION Z(5000)
LEVEL 2,Z
READ(IU)NTS
DO 50 I=1,24
LABL(M,N,I)=NTS(I)
50 CONTINUE
WRITE(6,3)M,N,(LABL(M,N,I),I=1,24)
READ(IU)NPT
READ(IU)TSTART,DTIME
WRITE(6,2)NPT,TSTART,DTIME
READ(IU)(Z(I),I=1,NPT)
RETURN
2 FORMAT(I10,2F10.5)
3 FORMAT(1X,2I2,1X,24A2)
END
SUBROUTINE DIFFER

CALC FIRST AND SECOND DERIVATIVES

COMMON/I/MIN(6),NIN(6),NTS(24),NCH,IDERIV,IFILT,NPT,LDEL
* ,NLSQ,LABEL(10),LABL(3,2,24),Lcntl(2,7)
REAL LDEL
COMMON/LEV1/DTIME,CT(3,2),CT1(3,2),CT2(3,2),CT3(3,2),CVT(3,6)
* ,TSTART,ZZ(3,2)
COMMON/LEV2C/DAT(3,2,5000),DATD(3,2,5000),DATDD(3,2,5000)
LEVEL 2,DAT,DATD,DATDD
DO 500 I=1,NCH
M=MIN(I)
N=NIN(I)
DO 100 J=1,NPT
DATD(M,N,J)=DAT(M,N,J)
100  CONTINUE
ITYPE=2
CALL FILT(DATD,M,N,NPT,ITYPE)
DO 150 J=1,NPT
DATD(M,N,J)=DATD(M,N,J)/DTIME
150  CONTINUE
WRITE(6,1)(LABL(M,N,J),J=1,24)
ITYPE=1
20
CALL FILT(DATD,M,N,NPT,ITYPE)
WRITE(6,2)(LABL(M,N,J),J=1,24)
DO 200 J=1,NPT
DATDD(M,N,J)=DATD(M,N,J)
200  CONTINUE
ITYPE=2
CALL FILT(DATDD,M,N,NPT,ITYPE)
DO 250 J=1,NPT
DATDD(M,N,J)=DATDD(M,N,J)/DTIME
250  CONTINUE
WRITE(6,1)(LABL(M,N,J),J=1,24)
ITYPE=1
30
CALL FILT(DATDD,M,N,NPT,ITYPE)
WRITE(6,2)(LABL(M,N,J),J=1,24)
DO 350 J=1,NPT
DATDD(M,N,J)=DATD(M,N,J)
350  CONTINUE
ITYPE=2
CALL FILT(DATDD,M,N,NPT,ITYPE)
WRITE(6,2)(LABL(M,N,J),J=1,24)
DO 500 J=1,NPT
DATDD(M,N,J)=DATDD(M,N,J)
500  CONTINUE
RETURN
1 FORMAT(' CHANNEL ',24A2,' HAS BEEN DIFFERENTIATED')
2 FORMAT(' CHANNEL ',24A2,' HAS BEEN FILTERED')
END
SUBROUTINE DISS4(X,Y1,Y2,Y3,NPT,LABEL,X4,Y4,N4)

GENERATES PLOT USING DISSPLA (VERSION 8.2)

DIMENSION LABEL(10),X(NPT),Y1(NPT),Y2(NPT),Y3(NPT),X4(N4),Y4(N4)
X0RIG=X(1)
XSTP='SCALE'
XMAX=X(NPT)
YORIG=1.E100
YSTP='SCALE'
YMAX=-1.E100
DO 200 I=1,NPT
  IF(Y1(I).LT.YMAX)G0 TO 100
  YMAX=Y1(I)
100  IF(Y1(I).GT.Y0RIG)G0 TO 200
  Y0RIG=Y1(I)
200  CONTINUE
  IF(YORIG.EQ.YMAX)YMAX=YMAX+.01
  WRITE(6,1)NPT,X0RIG,XMAX,Y0RIG,YMAX
1  FORMAT(I5,4E15.5)
  CALL HEIGHT(.28)
  J=J+1
  CALL BGNPL(J)
  CALL PHYSORC(1.,1.)
  CALL XINTAX
  CALL SETCLR('BLACK')
  CALL TITLE(LABEL(7),-11,'L',1,,'5,9,6.5')
  CALL GRAF(X0RIG,XSTP,XMAX,Y0RIG,YSTP,YMAX)
  IMARK=0
  CALL SETCLR('BLUE')
  CALL CURVE(X,Y1,NPT,IMARK)
  CALL SETCLR('RED')
  CALL DASH
  IF(Y2(1).NE.1.E100)CALL CURVE(X,Y2,NPT,IMARK)
  CALL RESET('DASH')
  CALL SETCLR('GREEN')
  CALL DOT
  IF(Y3(1).NE.1.E100)CALL CURVE(X,Y3,NPT,IMARK)
  CALL RESET('DOT')
40 IMARK=-1 CALL SETCLR('RED')
IF(N4.GT.0)CALL CURVE(X4,Y4,N4,IMARK)
CALL ENDPL(J)
RETURN

45 END
SUBROUTINE FILT(Z,M,N,NPT,ITYPE)

C INPUTS FIR COEFFICIENTS AND CONVOLVES THE DATA
C ITYPE = 1 - COEFFICIENTS ARE FOR A LOWPASS OR A HIGHPASS FILTER
C 2 - COEFFICIENTS ARE FOR A DIFFERENTIATOR

DIMENSION Z(3,2,5000),X(5000),H(512)
LEVEL 2,Z
PI2=6.283185307179865

DO 100 I=1,NPT
   X(I)=Z(M,N,I)
100 CONTINUE

IF(ITYPE.EQ.1)GO TO 150
   JTYP=2
   IU=4
   CALL COEF2(NFILT,H,IU,JTYP)
   DO 120 I=1,NFILT
      H(I)=H(I)*PI2
   120 CONTINUE
   REWIND IU
   GO TO 200
150 JTYP=1
   IU=17
   CALL COEF1(NFILT,H,IU)
   REWIND IU
200 CALL CONVOL(H,X,NPT,NFILT,JTYP)
   DO 300 I=1,NPT
      Z(M,N,I)=X(I)
300 CONTINUE

RETURN
END
SUBROUTINE ORIENT

READ CONTROL PARAMETERS
READ DATA INTO APPROPRIATE ARRAYS
CONVERT DATA, IF DESIRED
FILTER DATA, IF DESIRED

COMMON/I/MIN(6),NIN(6),NTS(24),NCH,IDERIV,IFILT,NPT,LDEL
*,NLSQ,LABEL(10),LABL(3,2,24),LCNT(2,7)
REAL LDEL
COMMON/LEV1/DTIME,CT(3,2),CT1(3,2),CT2(3,2),CT3(3,2),CVT(3,6)
*,TSTART,ZZ(3,2)
COMMON/LEV2C/DAT(3,2,5000),DATD(3,2,5000),DATDD(3,2,5000)
LEVEL 2,DAT,DATD,DATDD
COMMON/LEV2D/Z(5000)
LEVEL 2,Z
READ(5,1)NCH,ICVT,IFILT,IDERIV
WRITE(6,6)NCH,ICVT,IFILT,IDERIV
IF(IDERIV.EQ.0)JL=3
IF(IDERIV.EQ.1)JL=1
WRITE(6,5)
DO 150 J=1,JL
DO 100 I=1,NCH
READ(5,1)MIN(I),NIN(I),IU
WRITE(6,1)MIN(I),NIN(I),IU
M=MIN(I)
N=NIN(I)
CALL DATAIN(M,N,Z,IU)
IF(J.EQ.2)GO TO 70
IF(J.EQ.3)GO TO 90
DO 60 K=1,NPT
DAT(M,N,K)=Z(K)
60 CONTINUE
GO TO 100
35 DO 80 K=1,NPT
DATD(M,N,K)=Z(K)
80 CONTINUE
GO TO 100
90 DO 95 K=1,NPT
DATDD(M,N,K) = Z(K)

CONTINUE

CONTINUE

CONTINUE

IF(ICVT.EQ.0) GO TO 325

WRITE(6,7)

READ(5,3)(CVT(1,J), J=1, 6)

WRITE(6,3)(CVT(1,J), J=1, 6)

READ(5,3)(CVT(2,J), J=1, 2)

WRITE(6,3)(CVT(2,J), J=1, 2)

READ(5,3)(CVT(3,J), J=1, 2)

WRITE(6,3)(CVT(3,J), J=1, 2)

DO 300 I=1, 3

DO 300 J=1, 2

READ(5,2)M,N,CT1(M,N),CT2(M,N),CT3(M,N)

CT(M,N) = CT1(M,N)/CT2(M,N)/CT3(M,N)

WRITE(6,2)M,N,CT1(M,N),CT2(M,N),CT3(M,N),CT(M,N)

CONTINUE

ISW=0

DO 400 I=1,NCH

M=MIN(I)

N=NIN(I)

IF(ICVT.EQ.0) GO TO 350

CALL CONVT(M,N,ISW)

IF(IFILT.EQ.0) GO TO 400

ITYPE=1

CALL FILT(DAT,M,N,NPT,ITYPE)

WRITE(6,4)(LABL(M,N,J), J=1, 3)

CONTINUE

RETURN

1 FORMAT(4I3)

2 FORMAT(2I3,4F10.5)

3 FORMAT(8F10.5)

4 FORMAT( ' CHANNEL ',3A2,' HAS BEEN FILTERED' )

5 FORMAT( ' // INPUT DATA CHANNELS' )

6 FORMAT( ' NCH = ',I3,' ICVT = ',I3,' IFILT = ',I3,' IDERIV = ',I3 )

7 FORMAT( ' // CALIBRATION CONSTANTS' )

END
SUBROUTINE PLOT4(DAT)

PUTS 3-DIMENSIONAL ARRAY INTO 1-DIMENSIONAL ARRAYS FOR PLOTTING

DIMENSION DAT(3,2,5000)
LEVEL 2,DAT
COMMON/1/ MIN(6), NIN(6), NTS(24), NCH, IDERIV, IFILT, NPT, LDEL
* , NLSQ, LABEL(10), LABL(3,2,24), LCNT(2,7)
REAL LDEL
COMMON DUM(1),
* , X(5000), Y1(5000), Y2(5000), Y3(5000), Y4(5000), Y5(5000), Y6(5000)
DUM(1)=1.E100
NPLT=2500
N4=0
ENCODE(11,1, LABEL(7))(LABL(1,1,J), J=1,3)
DO 100 J=1,NPLT
X(J)=J
Y1(J)=DAT(MIN(1), NIN(1), J)
IF(MIN(3).NE.0) Y2(J)=DAT(MIN(3), NIN(3), J)
IF(MIN(5).NE.0) Y3(J)=DAT(MIN(5), NIN(5), J)
Y4(J)=DAT(MIN(2), NIN(2), J)
IF(MIN(4).NE.0) Y5(J)=DAT(MIN(4), NIN(4), J)
IF(MIN(6).NE.0) Y6(J)=DAT(MIN(6), NIN(6), J)
100 CONTINUE
IF(MIN(3).EQ.0) Y2(1)=DUM(1)
IF(MIN(4).EQ.0) Y5(1)=DUM(1)
IF(MIN(5).EQ.0) Y3(1)=DUM(1)
IF(MIN(6).EQ.0) Y6(1)=DUM(1)
ENCODE(11,1, LABEL(7))(LABL(1,1,J), J=1,3)
CALL DISS4(X,Y1,Y2,Y3,NPLT, LABEL, X4, Y4, N4)
ENCODE(11,1, LABEL(7))(LABL(1,2,J), J=1,3)
CALL DISS4(X,Y4,Y5,Y6,NPLT, LABEL, X4, Y4, N4)
RETURN
1 FORMAT(3A2,5X)
END
SUBROUTINE WRDAT

WRITES ALL PROCESSED DATA ONTO OUTPUT FILE TO BE SAVED FOR LATER USE

COMMON/LEV2C/DAT(3,2,5000),DATD(3,2,5000),DATDD(3,2,5000)
LEVEL 2,DAT,DATD,DATDD
COMMON/I/MIN(6),NIN(6),NTS(24),NCH,IDERIV,IFILT,NPT,LDEL
* ,NLSQ,LABEL(10),LABL(3,2,24),LCNT(2,7)
REAL LDEL

COMMON/LEV1/DTIME,CT(3,2),CT1(3,2),CT2(3,2),CT3(3,2),CVT(3,6)
* ,TSTART,ZZ(3,2)
IF(IFILT.EQ.0)WRITE(6,2)
IF(IFILT.NE.0)WRITE(6,5)
DO 200 I=1,NCH
DO 100 J=1,24
NTS(J)=LABL(MIN(I),NIN(I),J)
100 CONTINUE
WRITE(18)NTS
WRITE(6,1)NTS
WRITE(18)NPT
WRITE(18)TSTART,DTIME
WRITE(18)(DAT(MIN(I),NIN(I),J),J=1,NPT)
200 CONTINUE
IF(IDERIV.EQ.0)GO TO 700
WRITE(6,3)
DO 400 I=1,NCH
DO 300 J=1,24
NTS(J)=LABL(MIN(I),NIN(I),J)
300 CONTINUE
WRITE(18)NTS
WRITE(6,1)NTS
WRITE(18)NPT
WRITE(18)TSTART,DTIME
WRITE(18)(DATD(MIN(I),NIN(I),J),J=1,NPT)
400 CONTINUE
WRITE(6,4)
DO 600 I=1,NCH
DO 500 J=1,24
NTS(J)=LABL(MIN(I),NIN(I),J)
        40 CONTINUE
WRITE(18)NTS
WRITE(6,1)NTS
WRITE(18)NPT
WRITE(18)TSTART,DTIME
        45 CONTINUE
WRITE(18)(DATDD(MIN(I),NIN(I),J),J=1,NPT)
        600 CONTINUE
700 RETURN
1 FORMAT(5X,' WRITING ON FILE - ',24A2)
2 FORMAT(//,' INPUT DATA - UNFILTERED')
3 FORMAT(' FIRST DERIVATIVE - FILTERED')
4 FORMAT(' SECOND DERIVATIVE - FILTERED')
5 FORMAT(//,' INPUT DATA - FILTERED')
END
APPENDIX C

C.1.3. Card Image Formats That Are Required For The Input Data Section Of MFA File MUZMO40/UN=BOOTS

<table>
<thead>
<tr>
<th>Card</th>
<th>Condition*</th>
<th>Column</th>
<th>Format</th>
<th>Variable</th>
<th>Calling Subroutine</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-3</td>
<td>I3</td>
<td></td>
<td>IPLT1</td>
<td>MAIN</td>
<td>If IPLT1=1, displacements are plotted</td>
</tr>
<tr>
<td></td>
<td>4-6</td>
<td>I3</td>
<td></td>
<td>IPLT2</td>
<td></td>
<td>If IPLT2=1, velocities are plotted</td>
</tr>
<tr>
<td></td>
<td>7-9</td>
<td>I3</td>
<td></td>
<td>IPLT3</td>
<td></td>
<td>If IPLT3=1, accelerations are plotted</td>
</tr>
<tr>
<td></td>
<td>10-12</td>
<td>I3</td>
<td></td>
<td>IPRT</td>
<td></td>
<td>If IPRT=1, displacements, velocities and accelerations are written on a file on tape unit 18.</td>
</tr>
<tr>
<td>2</td>
<td>1-3</td>
<td>I3</td>
<td></td>
<td>NCH</td>
<td>ORIENT</td>
<td>Number of data sets to be inputted</td>
</tr>
<tr>
<td></td>
<td>4-6</td>
<td>I3</td>
<td></td>
<td>ICVT</td>
<td></td>
<td>If ICVT ≠0, data conversion is done</td>
</tr>
<tr>
<td></td>
<td>7-9</td>
<td>I3</td>
<td></td>
<td>IFILT</td>
<td></td>
<td>If IFILT ≠0, displacements are filtered</td>
</tr>
<tr>
<td></td>
<td>10-12</td>
<td>I3</td>
<td></td>
<td>IDERIV</td>
<td></td>
<td>If IDERIV ≠0, differentiation is done</td>
</tr>
<tr>
<td>3</td>
<td>1-3</td>
<td>I3</td>
<td></td>
<td>MIN(I)</td>
<td>ORIENT</td>
<td>First index for placement of data into array DAT</td>
</tr>
<tr>
<td></td>
<td>4-6</td>
<td>I3</td>
<td></td>
<td>MIN(I)</td>
<td></td>
<td>Second index for placement of data into array DAT</td>
</tr>
<tr>
<td></td>
<td>7-9</td>
<td>I3</td>
<td></td>
<td>IU</td>
<td></td>
<td>Tape unit number on which data file resides</td>
</tr>
</tbody>
</table>

4. Repeat card 3 until NCH cards are inputted.

5. Repeat sets of cards 3 and 4 for JL sets: JL=3 if IFILT = 0 or JL=1 if IFILT = 1.

*Omit the card if condition is not met.
<table>
<thead>
<tr>
<th>CARD</th>
<th>CONDITION</th>
<th>COLUMN</th>
<th>FORMAT</th>
<th>VARIABLE</th>
<th>CALLING SUBROUTINE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>ICVT ≠ 0</td>
<td>1-10</td>
<td>F10.5</td>
<td>CVT(1,1)</td>
<td>ORIENT</td>
<td>Coefficients for conversion of data of sensor 1 [conversion is nonlinear, as in Eq. (3.2)]</td>
</tr>
<tr>
<td></td>
<td>11-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>21-20</td>
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<td></td>
<td>31-40</td>
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<td>41-50</td>
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<tr>
<td></td>
<td>51-60</td>
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<td></td>
</tr>
<tr>
<td>7</td>
<td>ICVT ≠ 0</td>
<td>1-10</td>
<td>F10.5</td>
<td>CVT(2,1)</td>
<td>ORIENT</td>
<td>Coefficients for conversion of data of sensor 2 [conversion is linear]</td>
</tr>
<tr>
<td></td>
<td>11-20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>ICVT ≠ 0</td>
<td>1-10</td>
<td>F10.5</td>
<td>CVT(3,1)</td>
<td>ORIENT</td>
<td>Coefficients for conversion of data of sensor 3 [conversion is linear]</td>
</tr>
<tr>
<td></td>
<td>11-20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9**</td>
<td>ICVT ≠ 0</td>
<td>1-3</td>
<td>I3</td>
<td>M</td>
<td>ORIENT</td>
<td>First index of arrays CT1, CT2, CT3 Second index of arrays CT1, CT2, CT3 Transducer calibration factors</td>
</tr>
<tr>
<td>4-6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-16</td>
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<tr>
<td>17-26</td>
<td></td>
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</tr>
<tr>
<td>27-36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>ICVT ≠ 0</td>
<td>Repeat</td>
<td></td>
<td></td>
<td></td>
<td>Repeat card 9 until 6 cards are inputted.</td>
</tr>
</tbody>
</table>

**Since these data sets had not been previously converted into voltages so this input card was incorporated into the calculations such that CT(M,N) = CT1(M,N)/CT2(M,N)/CT3(M,N). The data are then multiplied by the appropriate CT before the other conversion is done.**
C.1.4. Output

The normal printed output of this program is mainly informative and diagnostic. The output consists of:

1. Input variables;
2. Identification of input data channels;
3. Calibration constants;
4. Lowpass filter coefficients (when used first time);
5. Differentiator coefficients (when used first time); and
6. Path each channel follows as it is differentiated, filtered, and/or written on an output file.

The plotted output consists of sets of two plots: one for horizontal data and one for vertical. The number of curves on each plot is determined by the array MIN. The number of sets plotted is determined by the variables IPLT1, IPLT2, and IPLT3.
C.2. Program MUZPRED

C.2.1. Listing Of Job Control Language Of MFA File MUZPRED/UN=BOOTS

BOOTS,T200.
USER,ROOTS,XXXXXX.
CHARGE,PDXXX,PD.
ATTACH,DISSPL9/UN=DISSPLA.
ATTACH,IMSL/UN=LIBRARY.
LIBRARY,DISSPL9,IMSL.
FTN,L=0.
GET,A=DFFATR.
FTN,I=A,L=0.
ATTACH,TAPE1=DVA05.
GET,TAPE2=DFF1.
GET,TAPE3=DISPL40.
ATTACH,TAPE4=DVA05U.
GET,TAPE7=RECL40.
GET,TAPE8=LPF62.
GET,TAPE10=UVECT40.
LGO.
REPLACE,TAPE9=MUZPT05.
REPLACE,META=DISS05R.
EXIT.
REPLACE,META=DISSERR.
C.2.2. Listing of FORTRAN Program

```fortran
PROGRAM DISS9(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE1,TAPE2,
               TAPE3,TAPE4,TAPE7,TAPE8,TAPE9,TAPE10,META,TAPE13)

C ANA\LYSIS OF MUZZLE MOTION DATA - PROGRAM 2
C
C PLOTTING IN COLOR USING DISSPLA 9.0 ON A TEKTRONIX 4107 TERMINAL
C
COMMON/LEV1/DAT(6,2,2500),LABL(3,2,24),MIN(9),MIN(9),TSTART,DTIME,
              NPT,NPLT,LKEY
DIMENSION LABEL(IO)

LABEL(1)=10H BOOTS
LABEL(2)=10H BLDG.390
LABEL(3)=10H 6121
LABEL(4)=10H DISSPLA9.0

CALL COMPRS
CALL SETDEV(13,13)
WRITE(6,1)
READ(5,2)NCH,NPLOTP,NPLOTC,NPLOTU,IPRINT
IF(EOF(5).NE..0)GO TO 200
20. WRITE(6,7)NCH,NPLOTP,NPLOTC,NPLOTU,IPRINT
DO 110 I=1,NCH
   READ(5,2)MIN(I),NIN(I),IU
   WRITE(6,6)MIN(I),NIN(I),IU
   IF(IU.EQ.0)IU=1
25   CALL DATAIN(MIN(I),NIN(I),IU)
110  CONTINUE
READ(5,3)LKEY
WRITE(6,4)LKEY
CALL PREDCT(NPLOTP)
30   CALL CALCZ(NPLOTCP,NPLOTU,IPRINT)
200  CALL DONEPL
STOP
1 FORMAT(1H1)
2 FORMAT(20I3)
3 FORMAT(16I5)
4 FORMAT(//,' LKEY = ',15)
5 FORMAT(' MIN, NIN, IU ',2013)
7 FORMAT( ' NCH, NPLOTP, NPLOTC, NPLOTU, IPRINT ',2013)
END
```
SUBROUTINE CALCZ(NPLOTC,NPLOTU,IPRINT)

THIS SUBROUTINE SCALES A SET OF RECOIL MOTION DATA FROM A SIMILAR
FIRING TO THE TIME OF THIS FIRING, CALCULATES THE DISPLACEMENT IN
THE Z-DIRECTION OF EACH COMPONENT (HORIZONTAL AND VERTICAL) AT EACH
DISCRETE TIME, DIFFERENTIATES THIS RESULTING DISPLACEMENT, AND
PLOTS THE RESULTS IF NPLOT .NE. 0.

DIMENSION C(10), MDAT(9), NDAT(9), AA(3,3), BB(3), COEF(3), IWK(50),
WRK(50), Z(3,2), ZZ(2500)
* COMMON/LEV1/DAT(6,2,2500), LABL(3,2,24), MIN(9), NIN(9), TSTART, DTIME,
* NPT, NPLT, LKEY

LZM = MODEL L(START OF MOTION)
LPM = MODEL L(PEAK PRESSURE)
LEM = MODEL L(SHOT EJECTION)

LPD = DATA L(PEAK PRESSURE)
LED = DATA L(SHOT EJECTION)
LZD IS THEN DETERMINED BY SCALING THE TWO SETS OF PARAMETERS

READ(5,1) LZM, LPM, LEM
READ(5,1) LPD, LED
RAT = FLOAT(LEM - LZM)/FLOAT(LEM - LPM)
LZD = FLOAT(LED) - RAT*FLOAT(LED - LPD)
RLSPAN = LED - LZD
WRITE(6,6)
WRITE(6,1) LZM, LPM, LEM
WRITE(6,1) LZD, LPD, LED

DO 200 L = 1, NPT

DAT(6,1,L) = .0
DAT(6,2,L) = .0
FL = FLOAT(L - LZD)/RLSPAN
IF(L.LE.LZD)GO TO 200
DO 100 M=1,MPP
DAT(6,1,L)=DAT(6,1,L)+C(M)*FL**(M-1)
DAT(6,2,L)=DAT(6,2,L)+C(M)*FL**M/FLOAT(M)
100 CONTINUE
DAT(6,2,L)=DAT(6,2,L)*RLSPAN*DTIME
IF(DAT(6,1,L).LT.RVMAX)GO TO 260
RVMAX=DAT(6,1,L)
200 CONTINUE
260 DO 270 LL=L,NPT
DAT(6,1,LL)=RVMAX
DAT(6,2,LL)=DAT(6,2,LL-1)+RVMAX*DTIME
270 CONTINUE
READ(5,2)Z(1,1),Z(1,2),Z(2,1),Z(3,1)
Z(2,2)=Z(2,1)
Z(3,2)=Z(3,1)
WRITE(6,8)
WRITE(6,2)Z
C TEMPORARY - THE VARIABLE CONV IS NECESSARY TO CHANGE THE RECOIL
DATA FROM MILLIMETERS TO CENTIMETERS
C
CONV=.1
C
DO 450 L=1,NPT
DO 350 K=1,3
AA(K,1)=1.
AA(K,2)=Z(K,1)+CONV*DAT(6,2,L)
AA(K,3)=AA(K,2)**4
BB(K)=DAT(K,1,L)
350 CONTINUE
TOL=.0
KBASIS=0
CALL LLSQF(AA,3,3,3,BB,TOL,KBASIS,COEF,WRK,IWK,IER)
DAT(4,1,L)=COEF(1)
DAT(5,1,L)=COEF(2)
DAT(1,1,L)=COEF(3)
DO 400 K=1,3
AA(K,1)=1.
AA(K,2) = Z(K,2) + CONV*DAT(6,2,L)
AA(K,3) = AA(K,2)**4
BR(K) = DAT(K,2,L)

CONTINUE
TOL = .0
KRAS = 0

CALL ILSSOF(AA,3,3,BB,TOL,KRAS,COEF,WRK,WRK,IFR)
DAT(4,2,L) = COEF(1)
DAT(5,2,L) = COEF(2)
DAT(1,2,L) = COEF(3)

CONTINUE
READ(5,4)NZREF
WRITE(6,10)NZREF
DO 480 I = 1,NZREF
READ(5,2)ZREF
WRITE(6,11)ZREF

DO 454 L = 1,NPT
DAT(2,1,L) = DAT(4,1,L) + DAT(5,1,L)*ZREF + DAT(1,1,L)*ZREF**4
DAT(2,2,L) = DAT(4,2,L) + DAT(5,2,L)*ZREF + DAT(1,2,L)*ZREF**4
DAT(3,1,L) = DAT(5,1,L) + 4.*DAT(1,1,L)*ZREF**3
DAT(3,2,L) = DAT(5,2,L) + 4.*DAT(1,2,L)*ZREF**3

CONTINUE
TKEY = DTIME*FLOAT(LKEY)
TST = -1. + TKEY
TSP = 2. + TKEY
LST = (TST - TSTART)/DTIME + 1.E-10 + 1.
LSP = (TSP - TSTART)/DTIME + 1.E-10
IU = 9
IF(IPRINT .EQ. 0) GO TO 455
NARR = 3
READ(5,4)(MDAT(II),NDAT(II),II = 1,NARR)
WRITE(6,9)(MDAT(II),NDAT(II),II = 1,NARR)
CALL WRFILE(DAT,MDAT,NDAT,NARR,TST,LST,LSP,LARL,DTIME,IU)

CONTINUE
DO 456 L = 1,NPT
ZZ(L) = DAT(1,1,L)

CONTINUE
DO 457 L = 1,NPT
DAT(1,1,L) = ZZ(L)
CONTINUE

IUD = INPUT TAPE UNIT FOR DIFFERENTIATOR
IUF = INPUT TAPE UNIT FOR FIR FILTER
IF IUD OR IUF = 0, THAT OPERATION IS NOT DONE.

IUD=2
IUF=8
DO 460 L=1,NPT
ZZ(L)=DAT(2,1,L)
CONTINUE
CALL DIFFER(ZZ,NPT,DTIME,IUD,IUF)
DO 462 L=1,NPT
DAT(3,1,L)=ZZ(L)
ZZ(L)=DAT(2,2,L)
CONTINUE
CALL DIFFER(ZZ,NPT,DTIME,IUD,IUF)
DO 464 L=1,NPT
DAT(3,2,L)=ZZ(L)
CONTINUE
IF(NPLOT.C.EQ.0)GO TO 480
WRITE(6,3)
NCURV=1
IUPLT=7
REWIND IUPLT
READ(IUPLT,5)TIMEL,TIMER
READ(IUPLT,4)LAXIS,ICOLOR
DO 470 II=1,NPLOT
ITYPE=0
IF(II.EQ.3.OR.II.EQ.6.OR.II.EQ.13)ITYPE=1
N4=1
IF(IITLE.EQ.1)N4=2
NCRV=NCURV*(ITYPE+1)
READ(IUPLT,4)(MDAT(K),NDAT(K),K=1,NCRV)
WRITE(6,9)(MDAT(K),NDAT(K),K=1,NCRV)
ISC=0
IF(II.EQ.4)ISC=1
IF(ITYPE.EQ.1)ISC=1
IF(II.EQ.6)TIMEL=-1.
IF(II.EQ.6)TIMER= 1.
CALL DATA4(NCURV, MDAT, NDAT, ISC, ITYPE, LAXIS, ICOLOR, N4, TIMEL, TIMER, * IUPLT)

CONTINUE
CONTINUE
RETURN

1 FORMAT(16I5)
2 FORMAT(8E10.3)
3 FORMAT(' PLOTTING IN SUBROUTINE CALCZ')
4 FORMAT(20I3)
5 FORMAT(2F5.0)
6 FORMAT(' SUBROUTINE CALCZ - SCALING PARAMETERS')
7 FORMAT(' COEFFICIENTS OF RECOIL MOTION CURVE')
8 FORMAT(' Z-ARRAY')
9 FORMAT(' "MDAT, NDAT" PAIRS -')
10 FORMAT(' NZREF =', I3)
11 FORMAT(' ZREF = ', F10.5)
END
SUBROUTINE DATAIN(M,N,IU)

INPUT EXPERIMENTAL DATA

COMMON/LEV1/DAT(6,2,2500),LABL(3,2,24),MIN(9),WIN(9),TSTART,DTIME,
* NPT,NPLT,LKEY
DIMENSION NTS(24),Z(4100)
READ(IU)NTS
DO 50 I=1,24
10 LABL(M,N,I)=NTS(I)
50 CONTINUE
WRITE(6,3)M,N,(LABL(M,N,I),I=1,24)
READ(IU)NDATA
READ(IU)TSTART,DTIME
IS" WRITE(6,1)NDATA,TSTART,DTIME
READ(IU)(Z(I),I=1,NDATA)
NPT=NDATA

NECESSARY BECAUSE OF CENTRAL MEMORY SIZE RESTRICTIONS

IF(NPT.GT.2500)NPT=2500

NPLT=NPT
DO 100 I=1,NPT
20 DAT(M,N,I)=Z(I)
100 CONTINUE
RETURN

1 FORMAT(' NDATA, TSTART, DTIME =',I10,2F10.5)
2 FORMAT(I10,2F10.5)
3 FORMAT(1X,2I2,1X,24A2)
END
SUBROUTINE DATA4(NCURV, MDAT, NDAT, ISC, ITYPE, LAXIS, ICOLOR, N4, TIMEL, * TIMER, IUPLT)

C
C THIS SUBROUTINE PREPARES THE DATA ARRAYS IN PROPER FASHION SO
C THAT A WIDE VARIETY OF PLOTS CAN BE GENERATED USING THE SAME
C PLOTTING SUBROUTINE.

DIMENSION MDAT(9), NDAT(9), X(2500), Y1(2500), Y2(2500), Y3(2500), * DUM(1), X4(8), Y4(8), LXNAME(2), LYNAME(2)

COMMON /LEV1/ DAT(6,2,2500), LABL(3,2,24), MIN(9), NIN(9), TSTART, DTIME, * NPT, NPLT, LKEY

X4(1) = .0
IF(N4.EQ.0)GO TO 40
READ(IUPLT,3)((X4(I),Y4(I)),I=1,N4)
DO 30 I=1,N4
    X4(I) = X4(I) * DTIME
30 CONTINUE
WRITE(6,6)((X4(I),Y4(I)),I=1,N4)

DUM(1) = 1.E100
TST = X4(1) + TIMEL
TSP = X4(1) + TIMER
LST = (TST - TSTART) / DTIME + 1.E-10 + 1.
LSP = (TSP - TSTART) / DTIME + 1.E-10
NPL0T = LSP - LST + 1
TSTRT = -X4(1)
X4(1) = .0

C SPECIAL CONDITION – IF N4 = 2, THE PLOT ORIGIN IS MADE AT THESE
C COORDINATES

IF(N4.EQ.2)N4=0

J=0
DO 100 L=LST,LSP
    J=J+1
    IF(ITYPE.EQ.1)GO TO 50
    X(J) = TSTRT + DTIME * FLOAT(L-1)
    Y1(J) = DAT(MDAT(1), NDAT(1), L)
IF(NCURV.GE.2) Y2(J)=DAT(MDAT(2),NDAT(2),L)
IF(NCURV.GE.3) Y3(J)=DAT(MDAT(3),NDAT(3),L)
GO TO 100

50   X(J)=DAT(MDAT(1),NDAT(1),L)
     Y1(J)=DAT(MDAT(2),NDAT(2),L)
     IF(NCURV.GE.2) Y2(J)=DAT(MDAT(3),NDAT(3),L)
     IF(N4.EQ.0) X(J)=X(J)-DAT(MDAT(1),NDAT(1),LKEY)
     IF(N4.EQ.0) Y1(J)=Y1(J)-DAT(MDAT(2),NDAT(2),LKEY)

100  CONTINUE
     IF(N4.EQ.0) WRITE(6,5) DAT(MDAT(1),NDAT(1),LKEY), DAT(MDAT(2),NDAT(2))
     * , LKEY)
     IF(NCURV.LT.2) Y2(1)=DUM(1)
     IF(NCURV.LT.3.AND.ITYPE.EQ.0) Y3(1)=DUM(1)
     ENCODE(10,1,TITLE)(LABL(MDAT(1),NDAT(1),J),J=1,3)
     WRITE(6,2)LST, LSP, X(1), X(NPLOT)
      
55   LXNAME(1)= ' ' 
      LYNAMES(1)= ' ' 
      LXNAME(2)= ' ' 
      LYNAMES(2)= ' ' 
      IF(LAXIS.EQ.1) READ(IUPLT,4)LXNAME,LYNAME
      IF(LAXIS.EQ.1) WRITE(6,4)LXNAME,LYNAME
      CALL DISS4(X,Y1,Y2,Y3,NPLOT,TITLE,X4,Y4,N4,ISC,ITYPE,LXNAME,LYNAME
      * , ICOLOR, IUPLT)
      RETURN

1  FORMAT(3A2,4X)
2  FORMAT(' PLOT LIMITS - ',2I5,2F10.4)
3  FORMAT(8F10.0)
4  FORMAT(8A10)
5  FORMAT(' COORDINATES AT SHOT EJECTION - ',2(E12.5,3X))
6  FORMAT(' SPECIAL COORDINATES',8F10.3)

70 END
SUBROUTINE DISS4(X,Y1,Y2,Y3,NPT,TITLE,X4,Y4,N4,ISC,ITYPF,LXNAME,
  * LYNANE,ICOLOR,IUPLT)

  ISC=0 SELF-SCALE
  =1 READ IN XORIG, XMAX, YORIG, YMAX

  ITYPE=0 NORMAL PLOT
  =1 POLAR PLOT

  ICOLOR=0 BLACK/WHITE
  =1 COLOR

DIMENSION X(NPT),Y1(NPT),Y2(NPT),Y3(NPT),X4(N4),Y4(N4)
  * RAT(10),LXNAME(2),LYNAME(2)

15 IF(ISC.NE.0)GO TO 300
XORIG=X(1)
XSTP='SCALE'
XMAX=X(NPT)
YORIG=1.E100
YSTP='SCALE'
YMAX=-1.E100
DO 200 I=1,NPT
IF(Y1(I).LT.YMAX)GO TO 100
YMAX=Y1(I)
25 100 IF(Y1(I).GT.YORIG)GO TO 200
YORIG=Y1(I)
    200 CONTINUE

C SPECIAL FOR THIS SET OF DATA
C
20 IF(YORIG.LT.-0)YORIG=YORIG*1.1
C
GO TO 400
300 READ(IUPLT,1)XORIG,XMAX,XSTP,YORIG,YMAX,YSTP
35 400 WRITE(6,2)XORIG,XSTP,XMAX,YORIG,YSTP,YMAX
    JJ=JJ+1
    CALL BASALF('STANDARD')
    CALL MIXALF('SPECIAL')
    CALL PHYSOR(1.5,1.)
CALL PAGE(11.,8.5)
CALL SETCLR('BLACK')
IF(ITYPE.EQ.0)CALL AREA2D(8.5,6.0)
IF(ITYPE.EQ.1)CALL AREA2D(6.0,6.0)
CALL HEIGHT(.25)
CALL HEADINTITLIE,10,1.5,1)
CALL XNAME(LXNAME,13)
CALL YNAME(LYNAME,13)
CALL GRAF(XORIG,XSTP,XMAX,YORIG,YSTP,YMAX)
IF(ITYPE.EQ.0)IMARK=0
IF(ITYPE.EQ.1)IMARK=100
IF(ITYPE.EQ.1.AND.N4.EQ.0)IMARK=25
IF(ICOLOR.EQ.1)CALL SETCLR('BLUE')
CALL CURVE(X,Y1,NPT,IMARK)
IF(ITYPE.EQ.0)GO TO  600
DO  500 II=1,NPT,50
     CALL RLVEC(X(II),Y1(TI),X(II+5),Y1(IT+5),2331)
500  CONTINUE
600   IF(ICOLOR.EQ.1)CALL SETCLR('RED')
     TL=.5
     NMRK=2
     RAT(1)=6.
     RAT(2)=4.
     IF(ICOLOR.EQ.0)CALL MRSC0D(TL,NMRK,RAT)
     IF(Y2(1).NE.1.E100.AND.ITYPE.EQ.0)CALL CURVE(X,Y2,NPT,IMARK)
     IF(Y2(1).NE.1.E100.AND.ITYPE.EQ.1)CALL CURVE(Y2,Y3,NPT,IMARK)
     CALL RESET('DOT')
     IF(ICOLOR.EQ.1)CALL SETCLR('GREEN')
     TL=.25
     IF(ICOLOR.EQ.0)CALL MRSC0D(TL,NMRK,RAT)
     IF(Y3(1).NE.1.E100.AND.ITYPE.EQ.0)CALL CURVE(X,Y3,NPT,IMARK)
     CALL RESET('DASH')
     IF(ICOLOR.EQ.1)CALL SETCLR('GREEN')
     IMARK=-1
     IF(N4.GT.0)CALL CURVE(X4,Y4,N4,IMARK)
     CALL ENDPJJ(JJ)
RETURN
1 FORMAT(6E10.3)
2 FORMAT(' PLOT SCALES - ',6E13.5)
END
SUBROUTINE PREDCT(NPLOTP)

C
C THIS SUBROUTINE DOES A STRAIGHT LINE EXTRAPOLATION OF DATA FROM
C SENSORS 2 AND 3 TO THE POSITION OF SENSOR 1 AND THEN THE DATA
C FROM THE PREDICTION IS COMPARED WITH THE DATA OF SENSOR 1. NEXT,
C THE MAGNITUDES AND PHASE ANGLES OF BOTH SETS OF DATA ARE CALCULATED.
C IN THE VICINITY OF LKEY (A TIME OF INTEREST, USUALLY SHOT EJECTION)
C THE DATA ARE AVERAGED OVER SHORT TIME SPANS AND THEIR MAGNITUDES
C AND PHASE ANGLES CALCULATED AND PRINTED. PLOTS ARE GENERATED IF
C NPLOTP .NE. 0.
C
DIMENSION AVG(4,10),AMPL(2,10),ANGL(2,10),MDAT(9),NDAT(9)
COMMON/LEV1/DAT(6,2,2500),LABL(3,2,24),MIN(9),NIN(9),TSTART,DTIME,
* NPT,NPLT,LKEY
PI2=6.283185307179865
READ(5,1)DZ31,DZ32
WRITE(6,2)DZ31,DZ32
RAT=DZ31/DZ32
DO 200 L=1,NPT
  DO 100 N=1,2
    DAT(4,N,L)=DAT(3,N,L)+RAT*(DAT(2,N,L)-DAT(3,N,L))
  100 CONTINUE
  DAT(6,1,L)=SORT(DAT(1,1,L)**2+DAT(1,2,L)**2)
  DAT(5,1,L)=SORT(DAT(4,1,L)**2+DAT(4,2,L)**2)
  IF(DAT(1,1,L).EQ.0.AND.DAT(1,2,L).EQ.0)DAT(1,2,L)=1.E-5
    DAT(6,2,L)=ATAN2(DAT(1,1,L),DAT(1,2,L))
  IF(DAT(4,1,L).EQ.0.AND.DAT(4,2,L).EQ.0)DAT(4,2,L)=1.E-5
    DAT(5,2,L)=ATAN2(DAT(4,1,L),DAT(4,2,L))
    IF(DAT(6,2,L).LT.5.0)DAT(6,2,L)=DAT(6,2,L)+PI2
    IF(DAT(5,2,L).LT.5.0)DAT(5,2,L)=DAT(5,2,L)+PI2
    DAT(6,2,L)=DAT(6,2,L)*360./PI2
    DAT(5,2,L)=DAT(5,2,L)*360./PI2
  200 CONTINUE
INC=7
IF(DTIME.EQ.0.2)INC=5
INTV=4
LINC=INC
IF(DTIME.EQ.0.2)LINC=2
LST=LKEY-INC-(INTV-1)*LINC+1
LSP=LKEY+INTV*LINC
WRITE(6,4)
J=0
DO 400 L=LST,LSP,LINC
J=J+1
S1=.0
S2=.0
S3=.0
S4=.0
DO 300 I=1,INC
S1=S1+DAT(1,1,L+I-1)
S2=S2+DAT(1,2,L+I-1)
S3=S3+DAT(4,1,L+I-1)
S4=S4+DAT(4,2,L+I-1)
300 CONTINUE
AVG(1,J)=S1/FLOAT(INC)
AVG(2,J)=S2/FLOAT(INC)
AVG(3,J)=S3/FLOAT(INC)
AVG(4,J)=S4/FLOAT(INC)
AMPL(1,J)=SQRT(AVG(1,J)**2+AVG(2,J)**2)
AMPL(2,J)=SQRT(AVG(3,J)**2+AVG(4,J)**2)
ANGL(1,J)=ATAN2(AVG(1,J),AVG(2,J))
ANGL(2,J)=ATAN2(AVG(3,J),AVG(4,J))
IF(ANGL(1,J).LT.0)ANGL(1,J)=ANGL(1,J)+PI2
IF(ANGL(2,J).LT.0)ANGL(2,J)=ANGL(2,J)+PI2
ANGL(1,J)=ANGL(1,J)*360./PI2
ANGL(2,J)=ANGL(2,J)*360./PI2
LMID=L+INC/2
WRITE(6,3)LMID,AVG(1,J),AVG(2,J),AMPL(1,J),ANGL(1,J),AVG(3,J),
* AVG(4,J),AMPL(2,J),ANGL(2,J)
400 CONTINUE
IF(NPLOTP.EQ.0)GO TO 600
WRITE(6,7)
IUPLT=3
READ(IUPLT,6)TIMEL,TIMER
READ(IUPLT,5)LAXIS,ICOLOR
NCURV=2
N4=1
DO 500 I=1,NPLOT

ISC=1

ITYPE=0
IF(I.GE.5)ITYPE=1
IF(I.GE.6)NCURV=1
NCRV=NCURV*(ITYPE+1)
READ(IUPLT,5)(MDAT(K),NDAT(K),K=1,NCRV)
WRITE(6,8)(MDAT(K),NDAT(K),K=1,NCRV)
NCVV=NCURV
IF(I.EQ.7)N4=2
CALL DATA4(NCVV,MDAT,NDAT,ISC,ITYPE,LAXIS,ICOLOR,N4,TIMEL,TIMER, 
* IUPLT)
500 CONTINUE
600 RETURN

1 FORMAT(8F10.2)

2 FORMAT(//,' DZ31, DZ32 ',2F10.2)

3 FORMAT(I5,9X,3F9.5,F12.2,10X,3F9.5,F12.2)

4 FORMAT(//,' HORIZONTAL VERTICAL MAGNITUDE ORIENTATION', 
* ' HORIZONTAL VERTICAL MAGNITUDE ORIENTATION')

5 FORMAT(20I3)

6 FORMAT(2F5.0)

7 FORMAT(//,' PLOTTING IN SUBROUTINE PREDCT')

8 FORMAT(//,' MDAT, NDAT PAIRS - ',20I3)

END
SUBROUTINE UNITV(NPLOTU,IPRINT,TST,LST,LSP,IU)

C
C THIS SUBROUTINE CALCULATES THE TRANSLATION AND ROTATION
C PARAMETERS AS DESCRIBED IN SECTION 3.2.3, EQ.(3.16) IN
C PARTICULAR

DIMENSION MDAT(9),NDAT(9)
COMMON/LEV1/DAT(6,2,2500),LARL(3,2,24),MIN(9),NIN(9),TSTART,DTIME,
* NPT,NPLT,LKEY

DO 400 J=1,3
DO 100 L=1,NPT
DEN=SQRT(1.+DAT(3,1,L)**2+DAT(3,2,L)**2)
DN=SQRT(1.+DAT(3,1,L)**2)
IF(J.GT.2)GO TO 60
15 DAT(1,1,L)=-DAT(3,2,L)/(DN*DEN)
DAT(6,1,L)=DAT(1,1,L)*DAT(3,1,L)
GO TO 100
60 IF(J.GT.1)GO TO 80
DAT(6,1,L)=1./DN
DAT(6,2,L)=0
DAT(1,1,L)=-DAT(3,1,L)*DAT(6,1,L)
GO TO 100
80 IF(J.GT.2)GO TO 100
DAT(1,1,L)=1./DEN
DAT(1,1,L)=-DAT(3,1,L)*DAT(1,1,L)
DAT(6,1,L)=DAT(3,1,L)*DAT(1,1,L)
DAT(6,2,L)=DAT(3,2,L)*DAT(1,1,L)
100 CONTINUE
IF(NPLOTU.EQ.0.0.OR.J.NE.3)GO TO 300
WRITE(6,3)
30 IUPLT=10
REWIND IUPLT
READ(IUPLT,2)TIMEL,TIMER
READ(IUPLT,1)LAXIS,ICOLOR
ISC=0
35 NCURV=1
DO 200 I=1,NPLOTU
ITYPE=0
IF(I.EQ.3)ITYPE=1
LAXIS=0
IF(I.LE.2)LAXIS=1
N4=1
IF(ITYPE.EQ.1)N4=2
NCRV=NCURV*(ITYPE+1)
READ(IUPLT,1)(MDAT(K),NDAT(K),K=1,NCRV)
WRITE(6,4)(MDAT(K),NDAT(K),K=1,NCRV)
ISC=0
IF(ITYPE.EQ.1)ISC=1
IF(I.EQ.3.OR.I.EQ.4)ISC=1
CALL DATA4(NCURV,MDAT,NDAT,ISC,ITYPE,LAXIS,ICOLOR,N4,TIMEL,TIMER, 
  * IUPLT)
200  CONTINUE
300  IF(IPRINT.EQ.0)GO TO 400
 NARR=3
 MDAT(1)=6
 MDAT(2)=6
 MDAT(3)=1
 NDAT(1)=1
 NDAT(2)=2
 NDAT(3)=1
 CALL WRFILE(DAT,MDAT,NDAT,NARR,TST,LST,LSP,LABL,OTIME,IU)
400  CONTINUE
500  RETURN
1  FORMAT(20I3)
2  FORMAT(2F5.0)
3  FORMAT(//,' PLOTTING IN SUBROUTINE UNITV')
4  FORMAT(//,' "MDAT, NDAT" PAIRS -',20I3)
END
SUBROUTINE WRFILE(DAT,MDAT,NDAT,NARR,TST,LST,LSP,LABL,DTIME,IU)

C

C THIS SUBROUTINE WRITES DATA ARRAYS TO AN OUTPUT FILE TO BE SAVED FOR FUTURE USE

C

NARR = NUMBER OF ARRAYS TO BE WRITTEN
MDAT AND NDAT CONTROL THE ORDER IN WHICH THE ARRAY IS WRITTEN
MDAT = FIRST INDEX OF 3-DIMENSIONAL ARRAY DAT
NDAT = SECOND INDEX OF 3-DIMENSIONAL ARRAY DAT

LST AND LSP CONTROL THE AMOUNT OF DATA WRITTEN BY SPECIFYING THE STARTING AND STOPPING ELEMENTS OF THE THIRD INDEX OF THE 3-DIMENSIONAL ARRAY DAT
LST = STARTING ELEMENT
LSP = STOPPING ELEMENT

DIMENSION DAT(6,2,2500),MDAT(9),NDAT(9),LABL(3,2,24),X(500)

DO 200 I=1,NARR
  K=0
  DO 100 L=LST,LSP
    K=K+1
    X(K)=DAT(MDAT(I),NDAT(I),L)
  100 CONTINUE
  WRITE(IU)(LABL(1,1,J),J=1,24)
  WRITE(IU)K

25 WRITE(IU)TST,DTIME
WRITE(IU)(X(J),J=1,K)
WRITE(6,1)MDAT(I),NDAT(I),(LABL(1,1,J),J=1,24)
200 CONTINUE
RETURN

1 FORMAT(' WRITING ARRAY ON FILE - INDICES ARE ',2I3,5X,24A2)
END
C.2.3. Listing Of Auxiliary FORTRAN Subroutines (MFA File DIFFATR)

1 SUBROUTINE DIFFER(Z,N,DTIME,IUD,IUF)
C
C IF IUD .NE. 0, THIS SUBROUTINE DIFFERENTIATES AN ARRAY USING AN
C FIR DIFFERENTIATOR; USUALLY, THE ONE IN FILE DIFF1 IS USED.
5 IF IUF .NE. 0, THEN THE ARRAY IS LOWPASS FILTERED.
C
DIMENSION Z(N),H(512)
PI2=6.283185307179865
10 IF(IUD.EQ.0)GO TO 150
C=PI2/DTIME
CALL COEF2(NFLT,H,IUD,JTPE)
REWIND IUD
DO 100 I=1,NFLT
15 H(I)=H(I)*C
100 CONTINUE
CALL CONVOL(H,Z,N,NFLT,JTPE)
150 IF(IUF.EQ.0)GO TO 200
CALL FILT(Z,N,IUF)
20 RETURN
END
SUBROUTINE COEF1(NFILT,H,IU)
C
C READS IN COEFFICIENTS OF AN FIR LOWPASS OR HIGHPASS FILTER
C
DIMENSION H(512)
READ(IU)NFILT,FP,TBWID,DP,DS
IF(ISW.NE.1)WRITE(6,1)
IF(ISW.NE.1)WRITE(6,2)NFILT,FP,TBWID,DP,DS
N=(NFILT+1)/2
READ(IU)(H(I),I=1,N)
IF(ISW.NE.1)WRITE(6,3)
IF(ISW.EQ.1)GO TO 200
DO 100 I=1,N,5
IST=I+4
IF(IST.GT.N)IST=N
WRITE(6,4)I,(H(II),II=I,IST)
100 CONTINUE
WRITE(6,5)
200 ISW=1
RETURN
END
SUBROUTINE COEF2(NFILT,H,IU,JTYPE)

READ IN COEFFICIENTS OF AN FIR DIFFERENTIATOR

DIMENSION H(64),EDGE(20),FX(10),WTX(10)
IF(ISW.NE.1)WRITE(6,1)
READ(IU)NFILT,JTYPE,NBANDS
IF(ISW.NE.1)WRITE(6,2)NFILT,JTYPE,NBANDS
JB=2*NBANDS
READ(IU)(EDGE(J),J=1,JB)
IF(ISW.NE.1)WRITE(6,5)(EDGE(J),J=1,JB)
READ(IU)(FX(J),J=1,NBANDS)
IF(ISW.NE.1)WRITE(6,6)(FX(J),J=1,NBANDS)
READ(IU)(WTX(J),J=1,NBANDS)
IF(ISW.NE.1)WRITE(6,7)(WTX(J),J=1,NBANDS)
READ(IU)(H(J),J=1,64)
IF(ISW.NE.1)WRITE(6,3)
IF(ISW.EQ.1)GO TO 200
N=NFILT/2+1
DO 100 I=1,N,5
IST=I+4
IF(IST.GT.N)IST=N
WRITE(6,4)I,(H(II),II=I,TST)
CONTINUE
WRITE(6,8)ISW=1
GO TO 200
WRITE(6,6)
RETURN
1 FORMAT(/,' FILTER PARAMETERS')
2 FORMAT(5X,' NFILT = ',5I5,' JTYPE = ',5I5,' NBANDS = ',5I5)
3 FORMAT(5X,' FILTER COEFFICIENTS')
4 FORMAT(5X,I5,5E15.8)
5 FORMAT(5X,' EDGE ',20F6.4)
6 FORMAT(5X,' FX ',10F6.2)
7 FORMAT(5X,' WTX ',10F7.1)
8 FORMAT(/)
END
SUBROUTINE CONVOL(H,X,NDIM,NFILT,JTYPE)

C THIS CONVOLUTION IS VALID ONLY FOR NFILT = ODD INTEGER
C NFILT MAX. SET TO 1023 - CAN BE RESET BE REDIMENSIONING ARRAYS
C IF JTYPE = 1, EVEN SYMMETRY ASSUMED FOR REFLECTION AT ENDPOINTS
C IF JTYPE = 2, ODD SYMMETRY ASSUMED FOR REFLECTION AT ENDPOINTS

DIMENSION H(512),X(NDIM),S(1030),T(1030)
C(JTYPE.EQ.1)SGN=1.
C(JTYPE.EQ.2)SGN=-1.
C(JTYPE.EQ.1)A=0.
C(JTYPE.EQ.2)A=2.
C(JTYPE.LT.1.OR.JTYPE.GT.2)WRITE(6,1)
C(JTYPE.LT.1.OR.JTYPE.GT.2)STOP

L=NFILT-1
NCOEF=NFILT/2+1
J=NCOEF
K=J-1
DO 10 I=1,NCOEF
S(I)=SGN*X(NCOEF-I+1)+A*X(1)
S(NFILT-I+1)=X(J)
T(NCOEF+I-1)=SGN*X(NDIM-I+1)+A*X(NDIM)
J=J-1
10 CONTINUE

DO 40 I=1,NDIM
X(I)=.0
DO 20 J=1,K
X(I)=X(I)+H(J)*(SGN*S(J)+S(NFILT-J+1))
20 CONTINUE

X(I)=X(I)+H(NCOEF)*S(NCOEF)
IF(I.EQ.NDIM)GO TO 50
DO 30 J=1,L
S(J)=S(J+1)
30 CONTINUE

IF(I.LE.NDIM-NCOEF)S(NFILT)=X(I+NCOEF)
IF(I.GT.NDIM-NCOEF)S(NFILT)=T(I+NFILT-NDIM+1)
40 CONTINUE

RETURN

1 FORMAT(' ERROR IN SUB CONVOL - JTYPE NOT EQUAL TO 1 OR 2')
END
SUBROUTINE FILT(X,NPT,LU)

C

THIS SUBROUTINE LOWPASS OR HIGHPASS FILTERS A DATA ARRAY

DIMENSION H(512),X(NPT)
JTyp=1
CALL COEF1(NFILT,H,LU)
REWIND LU
200 CALL CONVOL(H,X,NPT,NFILT,JTyp)
RETURN
END
C.2.4. Card Image Formats That Are Required For The Input Data Section of MFA File MUZPRED/UN=BOOTS

TABLE C.2. INPUT DATA FORMATS FOR TAPE UNIT 5

<table>
<thead>
<tr>
<th>Card</th>
<th>Condition*</th>
<th>Column</th>
<th>Format</th>
<th>Variable</th>
<th>Calling Subroutine</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1-3</td>
<td>I3</td>
<td>NCH</td>
<td>MAIN</td>
<td>No. of data sets to be inputted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-6</td>
<td>I3</td>
<td>NPLOTP</td>
<td></td>
<td>No. of plots to be generated in sub. PREDCT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7-9</td>
<td>I3</td>
<td>NPLTDC</td>
<td></td>
<td>No. of plots to be generated in sub. CALCZ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-12</td>
<td>I3</td>
<td>NPLTU</td>
<td></td>
<td>No. of plots to be generated in sub. UNITV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13-15</td>
<td>I3</td>
<td>IPRINT</td>
<td></td>
<td>If IPRINT ≠ 0, output data file is generated.</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1-3</td>
<td>I3</td>
<td>MIN(I)</td>
<td>MAIN</td>
<td>First index for placement of data into array DAT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-6</td>
<td>I3</td>
<td>NIN(I)</td>
<td></td>
<td>Second index for placement of data into array DAT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7-9</td>
<td>I3</td>
<td>IU</td>
<td></td>
<td>Tape unit no. on which data file resides</td>
</tr>
<tr>
<td>3</td>
<td>Repeat card 2 until NCH cards are inputted.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1-5</td>
<td>I5</td>
<td>LKEY</td>
<td>MAIN</td>
<td>Index at which to make time = 0.</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>1-10</td>
<td>F10.2</td>
<td>DZ31</td>
<td>PREDCT</td>
<td>Distance from sensor 3 to sensor 1, cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11-20</td>
<td>F10.2</td>
<td>DZ32</td>
<td>PREDCT</td>
<td>Distance from sensor 3 to sensor 2, cm</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>1-5</td>
<td>I5</td>
<td>LZM</td>
<td>CALCZ</td>
<td>Index of start of recoil motion (earlier experiment)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-10</td>
<td>I5</td>
<td>LPM</td>
<td></td>
<td>Index of peak pressure (earlier experiment)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11-15</td>
<td>I5</td>
<td>LEM</td>
<td></td>
<td>Index of shot exit (earlier experiment)</td>
</tr>
</tbody>
</table>

* Omit card if condition is not met.
<table>
<thead>
<tr>
<th>Card</th>
<th>Condition</th>
<th>Column</th>
<th>Format</th>
<th>Variable</th>
<th>Calling Subroutine</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td></td>
<td>1-5</td>
<td>I5</td>
<td>LPD</td>
<td>CALCZ</td>
<td>Index of peak pressure (this experiment)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-10</td>
<td>I5</td>
<td>LED</td>
<td></td>
<td>Index of shot exit (this experiment)</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>1-5</td>
<td>I5</td>
<td>MPOLY</td>
<td>CALCZ</td>
<td>Degree of polynomial to be inputted (earlier experiment)</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>1-10</td>
<td>E10.3</td>
<td>C(1)</td>
<td>CALCZ</td>
<td>Coefficients of polynomial (earlier experiment)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11-20</td>
<td>E10.3</td>
<td>C(2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>C(MPOLY+1)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>1-10</td>
<td>E10.3</td>
<td>Z(1,1)</td>
<td>CALCZ</td>
<td>Distance of sensor 1 (horiz) from muzzle face, cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11-20</td>
<td>E10.3</td>
<td>Z(1,2)</td>
<td></td>
<td>Distance of sensor 1 (vert.) from muzzle face, cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21-30</td>
<td>E10.3</td>
<td>Z(2,1)</td>
<td></td>
<td>Distance of sensor 2 from muzzle face, cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>31-40</td>
<td>E10.3</td>
<td>Z(3,1)</td>
<td></td>
<td>Distance of sensor 3 from muzzle face, cm</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>1-3</td>
<td>I3</td>
<td>NZREF</td>
<td>CALCZ</td>
<td>No. of times the displacement and muzzle-pointing calculations are to be done</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>1-10</td>
<td>E10.3</td>
<td>ZREF</td>
<td>CALCZ</td>
<td>Distance from muzzle face at which the displacement and muzzle-pointing calculations are to be done</td>
</tr>
<tr>
<td>Card</td>
<td>Condition</td>
<td>Column</td>
<td>Format</td>
<td>Variable</td>
<td>Calling Subroutine</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td>--------</td>
<td>--------</td>
<td>-----------</td>
<td>--------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>13</td>
<td>IPRINT≠0</td>
<td>1-3</td>
<td>I3</td>
<td>MDAT(1)</td>
<td>CALCZ</td>
<td>First index in array DAT of first set of data to be written to output file</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-6</td>
<td>I3</td>
<td>NDAT(1)</td>
<td></td>
<td>Second index in array DAT of first set of data to be written to output file</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7-9</td>
<td>I3</td>
<td>MDAT(2)</td>
<td></td>
<td>First index of second set</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-12</td>
<td>I3</td>
<td>NDAT(2)</td>
<td></td>
<td>Second index of second set</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13-15</td>
<td>I3</td>
<td>MDAT(3)</td>
<td></td>
<td>First index of third set</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16-18</td>
<td>I3</td>
<td>NDAT(3)</td>
<td></td>
<td>Second index of third set</td>
</tr>
</tbody>
</table>

14   Repeat cards 12 and 13 for NZREF times.
TABLE C.3. INPUT DATA FORMATS FOR TAPE UNITS 3, 7, AND 10

<table>
<thead>
<tr>
<th>Card</th>
<th>Condition*</th>
<th>Column</th>
<th>Format</th>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1-5</td>
<td>F5.0</td>
<td>TIMEL</td>
<td>Time to start plotting (time = .0 at LKEY), ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6-10</td>
<td>F5.0</td>
<td>TIMER</td>
<td>Time to stop plotting, ms</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>1-3</td>
<td>I3</td>
<td>LAXIS</td>
<td>=1 Plot axis labels to be inputted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>≠1 Plot axis labels are blank</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-6</td>
<td>I3</td>
<td>ICOLOR</td>
<td>=0 Black/white plot</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>=1 Color plot</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>1-3</td>
<td>I3</td>
<td>MDAT(1)</td>
<td>First index in array DAT of first set of data to be plotted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4-6</td>
<td>I3</td>
<td>NDAT(1)</td>
<td>Second index in array DAT of first set of data to be plotted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7-9</td>
<td>I3</td>
<td>MDAT(2)</td>
<td>First index of second curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10-12</td>
<td>I3</td>
<td>NDAT(2)</td>
<td>Second index of second curve</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Repeat cards 3 through 6 for NPLOTN, NPLOT, or NPLT times, depending on whether the calling subroutine is PREDCT, CALCZ, or UNITV.</td>
</tr>
<tr>
<td>4</td>
<td>N4&gt;0</td>
<td>1-10</td>
<td>F10.0</td>
<td>X4(1)</td>
<td>X-coordinate of a point to be symbol-plotted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11-20</td>
<td>F10.0</td>
<td>Y4(1)</td>
<td>Y-coordinate of a point to be symbol-plotted</td>
</tr>
<tr>
<td>5</td>
<td>LAXIS=1</td>
<td>1-10</td>
<td>A10</td>
<td>LXNAME</td>
<td>Label for x-axis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11-20</td>
<td>A10</td>
<td>LYNAME</td>
<td>Label for y-axis</td>
</tr>
<tr>
<td>6</td>
<td>ISC≠0</td>
<td>1-10</td>
<td>E10.3</td>
<td>XORIG</td>
<td>Minimum value of x-axis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11-20</td>
<td>E10.3</td>
<td>XMAX</td>
<td>Maximum value of x-axis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21-30</td>
<td>E10.3</td>
<td>XSTP</td>
<td>Interval between tic-marks on x-axis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>31-40</td>
<td>E10.3</td>
<td>YORIG</td>
<td>Minimum value of y-axis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41-50</td>
<td>E10.3</td>
<td>YMAX</td>
<td>Maximum value of y-axis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51-60</td>
<td>E10.3</td>
<td>YSTP</td>
<td>Interval between tic-marks on y-axis</td>
</tr>
</tbody>
</table>

* Omit card if condition is not met.
APPENDIX D

SAMPLE PROBLEM

As alluded to earlier in this report, the computer programs have been developed for the analysis of muzzle displacements collected in a collaborative experiment between BRL and RARDE in May and June 1984 at RARDE, Fort Halstead [5]. This experiment, carried out with a 40mm rifled gun, had the objective to assess the SDT measurement technique as a means to define projectile launch. It included the measurement of the projectile dynamics with respect to the muzzle during shot exit as well as the motion of the muzzle with respect to the ground. The latter was monitored by three orthogonal displacement transducers employing a SDT instrumentation for sensor 1 and electrooptical displacement transducers [A-8] for sensors 2 and 3. The three data sets for round #5 plus the muzzle recoil velocity recorded by an earlier experiment (see Section 4.3.1) form the input to the sample problem. Since the result of the analysis of the data from the collaborative experiment [6] will be discussed in a separate BRL technical report, only sample outputs including plots are shown for this round.
D.1. Program MUZMO40

D.1.1. Sample Input Card Images

0 0 0 1
6 1 0 1
1 1 1
1 2 2
2 1 8
2 2 9
3 1 10
3 2 11
202.52  .00221  .00444  215.11  .00349  .00221
108.9   242.1
263.9   227.8
1 1 .0024414  .9985  1.
1 2 .0024414  .99925  1.
2 1 .0048828  .99925  1.
2 2 .0048828  .99925  1.
3 1 .0048828  .9985  1.
3 2 .0048828  1.001  1.
APPENDIX D

D.1.2. Sample Printed Output (Program MUZMO40)

IPLT1 = 0  IPLT2 = 0  IPLT3 = 0  IPRT = 1
NCH =  6  ICVT =  1  IFILT =  0  IDERIV =  1

INPUT DATA CHANNELS
1  1  1
  1  1  BR0512  1  1  IBRL TUBE HOR
      4095    0.00000    0.01000

1  2  2
  1  2  BR0511  1  1  IBRL TUBE VERT
      4095    0.00000    0.01000

2  1  8
  2  1  BR0509  1  1  IHEL TUBE FWD HOR
      4095    0.00000    0.01000

2  2  9
  2  2  BR0508  1  1  IHEL TUBE FWD VERT
      4095    0.00000    0.01000

3  1 10
  3  1  BR0510  1  1  IHEL TUBE REAR HOR
      4095    0.00000    0.01000

3  2 11
  3  2  BR0507  1  1  IHEL TUBE REAR VERT
      4095    0.00000    0.01000
CALIBRATION CONSTANTS

202.52000  0.00221  0.00444  215.11000  0.00349  0.00221
108.90000  242.10000
263.90000  227.80000

FILTER PARAMETERS

NFILT = 31  JTYPE = 2  NRANDS = 1
EDGE 0.0000  .4000
FX 1.00
WTX 1.0
FILTER COEFFICIENTS

1  0.16166620E-04  -0.74131438E-04  0.21102257E-03  -0.49246632E-03  0.10096462E-02
6  -0.18862205E-02  0.32833366E-02  -0.54084061E-02  0.85345464E-02  -0.13047140E-01
11  0.19559239E-01  -0.29218184E-01  0.44647104E-01  -0.73733156E-01  0.15615738E+00
16 0.

CHANNEL BR0512

1 1 BRL TUBE HOR

HAS BEEN DIFFERENTIATED
FILTER PARAMETERS,
NFILT = 127 FP = .00500 TBWD = .01541 DP = .01000 DS = .01000
FILTER COEFFICIENTS
1  -.57611818E-02  -.13120665E-02  -.14458869E-02  -.15779811E-02  -.17054889E-02
6  -.18272020E-02  -.19407950E-02  -.20444951E-02  -.21345667E-02  -.22110148E-02
11 -.22686108E-02  -.23074309E-02  -.23235239E-02  -.23165943E-02  -.22816372E-02
16 -.22201999E-02  -.21269670E-02  -.20019212E-02  -.18400413E-02  -.16423613E-02
21 -.14040333E-02  -.11271255E-02  -.80807552E-03  -.45054632E-03  -.49316320E-04
26  .39177683E-03  .88090117E-03  .14120564E-02  .19883328E-02  .25922726E-02
31  .32498950E-02  .39438586E-02  .46685324E-02  .54340488E-02  .62277021E-02
36  .70536956E-02  .79036343E-02  .87790706E-02  .96719531E-02  .10582451E-01
41  .11502901E-01  .12431251E-01  .13361246E-01  .14291479E-01  .15214561E-01
46  .16127318E-01  .17023636E-01  .17900295E-01  .18750877E-01  .19572419E-01
51  .20359358E-01  .21108628E-01  .21814687E-01  .22474542E-01  .23082659E-01
56  .23637514E-01  .24135636E-01  .24573834E-01  .24947050E-01  .25256526E-01
61  .25501145E-01  .25673888E-01  .25780396E-01  .25814786E-01

CHANNEL BR0512  1 1 IBRL TUBE HOR  HAS BEEN FILTERED
CHANNEL BR0512  1 1 IBRL TUBE HOR  HAS BEEN DIFFERENTIATED
CHANNEL BR0512  1 1 IBRL TUBE HOR  HAS BEEN FILTERED
CHANNEL BR0512  1 1 IBRL TUBE HOR  HAS BEEN DIFFERENTIATED
CHANNEL BR0511  1 1 IBRL TUBE VERT  HAS BEEN DIFFERENTIATED
CHANNEL BR0511  1 1 IBRL TUBE VERT  HAS BEEN FILTERED
CHANNEL BR0511  1 1 IBRL TUBE VERT  HAS BEEN DIFFERENTIATED
CHANNEL BR0511  1 1 IBRL TUBE VERT  HAS BEEN FILTERED
CHANNEL BR0511  1 1 IBRL TUBE VERT  HAS BEEN DIFFERENTIATED
CHANNEL BR0509  1 1 HEL TUBE FWD HOR  HAS BEEN DIFFERENTIATED
CHANNEL BR0509  1 1 HEL TUBE FWD HOR  HAS BEEN FILTERED
CHANNEL BR0509  1 1 HEL TUBE FWD HOR  HAS BEEN DIFFERENTIATED
CHANNEL BR0509  1 1 HEL TUBE FWD HOR  HAS BEEN FILTERED
CHANNEL BR0508  1 1 HEL TUBE FWD VERT  HAS BEEN DIFFERENTIATED
CHANNEL BR0508  1 1 HEL TUBE FWD VERT  HAS BEEN FILTERED
CHANNEL BR0508  1 1 HEL TUBE FWD VERT  HAS BEEN DIFFERENTIATED
CHANNEL BR0508  1 1 HEL TUBE FWD VERT  HAS BEEN FILTERED
CHANNEL BR0510  1 1 HEL TUBE REAR HOR  HAS BEEN DIFFERENTIATED
CHANNEL BR0510  1 1 HEL TUBE REAR HOR  HAS BEEN FILTERED
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<tr>
<th>CHANNEL</th>
<th>INPUT DATA - UNFILTERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR0510</td>
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<td>BR0507</td>
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<td>BR0507</td>
<td>BR0510</td>
</tr>
<tr>
<td>BR0507</td>
<td>BR0512</td>
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</table>

<table>
<thead>
<tr>
<th>FIRST DERIVATIVE - FILTERED</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR0512</td>
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<td>BR0508</td>
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<td>BR0510</td>
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<tr>
<td>BR0507</td>
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</table>

<table>
<thead>
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<th>SECOND DERIVATIVE - FILTERED</th>
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<tbody>
<tr>
<td>BR0512</td>
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<tr>
<td>BR0508</td>
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<tr>
<td>BR0510</td>
</tr>
<tr>
<td>BR0507</td>
</tr>
</tbody>
</table>

END OF DISSPLA 8.2 — 0 VECTORS GENERATED IN 0 PLOT FRAMES.
-ISSCO-  4186 SORRENTO VALLEY BLVD., SAN DIEGO CALIF. 92121

DISSPLA IS A CONFIDENTIAL PROPRIETARY PRODUCT OF ISSCO AND ITS USE IS SUBJECT TO A NONDISSEMINATION AND NONDISCLOSURE AGREEMENT.
D.2. Program MUZPRED

D.2.1. Sample Input Card Images From Tape Unit 5 (Normal Input)

```
8   7   6   3   1
1   1   1
1   2   1
2   1   1
2   2   1
3   1   1
3   2   1
1   1   4
1   2   4
2059
   -45.36  -12.00
2175 2342 3474     .005
1490 2059
   -2.94   -3.25   -36.56   -48.56
2
   .0
6   2   2   1   2   2
   -7.52
6   2   2   1   2   2
```
D.2.2  Sample Input Card Images From Tape Unit 3 (MFA File DISPL40)

<table>
<thead>
<tr>
<th>TIME, MS</th>
<th>HORIZONTAL</th>
<th>VERTICAL</th>
<th>MAGNITUDE</th>
<th>ANGLE</th>
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<tr>
<td>-9.</td>
<td>3.</td>
<td>.06</td>
<td>.04</td>
<td>.02</td>
</tr>
<tr>
<td>1</td>
<td>24.2</td>
<td>1959.</td>
<td>2059.</td>
<td>.05</td>
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<tr>
<td>6151</td>
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<tr>
<td>1112</td>
<td>.0</td>
<td>2059.</td>
<td>2059.</td>
<td>.0</td>
</tr>
<tr>
<td>1112</td>
<td>.0</td>
<td>2059.</td>
<td>2059.</td>
<td>.0</td>
</tr>
<tr>
<td>1112</td>
<td>.0</td>
<td>2059.</td>
<td>2059.</td>
<td>.0</td>
</tr>
</tbody>
</table>
D.2.3. Sample Input Card Images From Tape Unit 7 (MFA File RECL40)

-9.  3.
  1 0
  2 1
    2059.  .0
    (0)MS(1)  (0)CM(1)
  2 2
    2059.  .0
    (0)MS(1)  (0)CM(1)
  2 1 2 2
    2059.  .0
    (0)CM(1)  (0)CM(1)
    -.02  .02  .01  -.02  .02  .01
  3 1
    2059.  .0
    (0)MS(1)  (0)CM/MS(1)
    -10.  4.  2.  -.015  .015  .005
  3 2
    2059.  .0
    (0)MS(1)  (0)CM/MS(1)
  3 1 3 2
    2059.  .0
    (0)CM/MS(1)  (0)CM/MS(1)
    -.02  .02  .01  -.02  .02  .01

96
D.2.4. Sample Input Card Images From Tape Unit 10 (MFA File UVECT40)

-1. 1.
1 0
6 1
2059. 0
(0)MS(1)
6 2
2059. 0
(0)MS(1)
6 1 6 2
2059. 0
-0.0005 0.0005 0.0005 -0.0005 0.0005 0.0005
APPENDIX D

D.2.5. Sample Printed Output (Program MUZPRED)

NCH, NPLOTU, NPLUTC, NPLOTU, IPRINT - 8 7 6 3 1
MIN, NIN, IU - 1 1 1
1 1 BRO512 1 1 1BRL TUBE HOR
NDATA, TSTART, DTIME - 4095 0.00000 .01000
MIN, NIN, IU - 1 2 1
1 2 BRO511 1 1 1BRL TUBE VERT
NDATA, TSTART, DTIME - 4095 0.00000 .01000
MIN, NIN, IU - 2 1 1
2 1 BRO509 1 1 1HEL TUBE FWD HOR
NDATA, TSTART, DTIME - 4095 0.00000 .01000
MIN, NIN, IU - 2 2 1
2 2 BRO508 1 1 1HEL TUBE FWD VERT
NDATA, TSTART, DTIME - 4095 0.00000 .01000
MIN, NIN, IU - 3 1 1
3 1 BRO510 1 1 1HEL TUBE HEARD HOR
NDATA, TSTART, DTIME - 4095 0.00000 .01000
MIN, NIN, IU - 3 2 1
3 2 BRO507 1 1 1HEL TUBE HEARD VERT
NDATA, TSTART, DTIME - 4095 0.00000 .01000
MIN, NIN, IU - 1 1 4
1 1 BRO512 1 1 1BRL TUBE HOR
NDATA, TSTART, DTIME - 4095 0.00000 .01000
MIN, NIN, IU - 1 2 4
1 2 BRO511 1 1 1BRL TUBE VERT
NDATA, TSTART, DTIME - 4095 0.00000 .01000

LKEY = 2059

DZ31, DZ32 -45.36 -12.00
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<th>BRL:</th>
<th>HORIZONTAL</th>
<th>VERTICAL</th>
<th>MAGNITUDE</th>
<th>ORIENTATION</th>
<th>HEL:</th>
<th>HORIZONTAL</th>
<th>VERTICAL</th>
<th>MAGNITUDE</th>
<th>ORIENTATION</th>
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<td>-0.06044</td>
<td>0.06489</td>
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<tr>
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<td>-0.02036</td>
<td>-0.06520</td>
<td>0.06830</td>
<td>197.34</td>
<td>-0.01292</td>
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<tr>
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<td>0.07530</td>
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<td>-0.06506</td>
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<td>0.07737</td>
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<td>0.06859</td>
<td>193.63</td>
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</tbody>
</table>

**PLOTTING IN SUBROUTINE PREDCT**

"MDAT, NDAT" PAIRS - 1 1 4 1
SPECIAL COORDINATES 20.590 0.000
PLOT LIMITS - 1160 2359 -9.0000 2.9900
TIME, MS HORIZONTAL
PLOT SCALES - -0.90000E+01 0.30000E+01 0.30000E+01 -0.60000E-01 0.20000E-01 0.40000E-01

"MDAT, NDAT" PAIRS - 1 2 4 2
SPECIAL COORDINATES 20.590 0.000
PLOT LIMITS - 1160 2359 -9.0000 2.9900
TIME, MS VERTICAL
PLOT SCALES - -0.90000E+01 0.30000E+01 0.30000E+01 -1.00000E+00 0.40000E-01 0.60000E-01

"MDAT, NDAT" PAIRS - 6 1 5 1
SPECIAL COORDINATES 20.590 0.050
PLOT LIMITS - 1160 2359 -9.0000 2.9900
TIME, MS MAGNITUDE
PLOT SCALES - -0.90000E+01 0.30000E+01 0.30000E+01 0 0.20000E-01 1.00000E+00

"MDAT, NDAT" PAIRS - 6 2 5 2
SPECIAL COORDINATES 20.590 260.000
PLOT LIMITS - 1160 2359 -9.0000 2.9900
TIME, MS ANGLE
PLOT SCALES - -0.90000E+01 0.30000E+01 0.30000E+01 0.60000E+02 1.00000E+03 3.60000E+03
"MDAT, NDAT" PAIRS - 1 1 1 2 4 1 4 2
SPECIAL COORDINATES 20.590 0.000
PLOT LIMITS - 1160 2359 -.0236 -.0291
HORIZONTAL VERTICAL
PLOT SCALES - -.80000E-01 .40000E-01 .80000E-01 -.10000E+00 .40000E-01 .60000E-01
"MDAT, NDAT" PAIRS - 1 1 1 2
SPECIAL COORDINATES 20.590 0.000
PLOT LIMITS - 1160 2359 -.0236 -.0291
HORIZONTAL VERTICAL
PLOT SCALES - -.80000E-01 .40000E-01 .80000E-01 -.10000E+00 .40000E-01 .60000E-01
"MDAT, NDAT" PAIRS - 1 1 1 2
SPECIAL COORDINATES 20.590 0.000 0.000 0.000
COORDINATES AT SHOT EJECTION - -.20104E-01 -.66116E-01
PLOT LIMITS - 1160 2359 -.0035 -.0090
HORIZONTAL VERTICAL
PLOT SCALES - -.20000E-01 .10000E-01 .30000E-01 -.20000E-01 .10000E-01 .30000E-01
SUBROUTINE CALCZ - SCALING PARAMETERS
2175 2342 3474
1406 1490 2059
COEFFICIENTS OF Recoil MOTION CURVE
-.337E-02 .377E+01 .420E+00 -.157E+02 .235E+02 -.104E+02
Z-ARRAY
-.294E+01 -.366E+02 -.486E+02 -.325E+01 -.366E+02 -.486E+02
NZREF = 2
ZREF = 0.00000
"MDAT, NDAT" PAIRS - 6 2 2 1 2 2
WRITING ARRAY ON FILE - INDICES ARE 6 2 BR0512 1 1 IBRL TUBE HOR
WRITING ARRAY ON FILE - INDICES ARE 2 1 BR0512 1 1 IBRL TUBE HOR
WRITING ARRAY ON FILE - INDICES ARE 2 2 BR0512 1 1 IBRL TUBE HOR
WRITING ARRAY ON FILE - INDICES ARE 6 1 BR0512 1 1 IBRL TUBE HOR
WRITING ARRAY ON FILE - INDICES ARE 6 2 BR0512 1 1 IBRL TUBE HOR
WRITING ARRAY ON FILE - INDICES ARE 1 1 BR0512 1 1 IBRL TUBE HOR
WRITING ARRAY ON FILE - INDICES ARE 6 2 BR0512 1 1 IBRL TUBE HOR
WRITING ARRAY ON FILE - INDICES ARE 1 1 BR0512 1 1 IBRL TUBE HOR
PLOTTING IN SUBROUTINE UNITV

"MDAT, NDAT" PAIRS - 6 1
SPECIAL COORDINATES 20.590 0.000
PLOT LIMITS - 1960 2159 -1.0000 .9900
(0)MS(1)
PLOT SCALES - -.10000E+01 .26257E+72 .99000E+00 -.53397E-03 .26257E+72 -.11864E-03

"MDAT, NDAT" PAIRS - 6 2
SPECIAL COORDINATES 20.590 0.000
PLOT LIMITS - 1960 2159 -1.0000 .9900
(0)MS(1)
PLOT SCALES - -.10000E+01 .26257E+72 .99000E+00 -.31739E-02 .26257E+72 -.10133E-02

"MDAT, NDAT" PAIRS - 6 1 6 2
SPECIAL COORDINATES 20.590 0.000 0.000 0.000
COORDINATES AT SHOT EJECTION - -.11864E-03 -.24520E-02
PLOT LIMITS - 1960 2159 -.0004 -.0002
PLOT SCALES - -.50000E-03 .50000E-03 .50000E-03
WRITING ARRAY ON FILE - INDICES ARE 6 1     BR0512
WRITING ARRAY ON FILE - INDICES ARE 6 2     BR0512
WRITING ARRAY ON FILE - INDICES ARE 1 1     BR0512

FILTER PARAMETERS
NFILT = 31  JTYPE = 2  NBANDS = 1
EDGE 0.0000 .4000
FX 1.00
WTX 1.0
FILTER COEFFICIENTS
<p>| | | | | |</p>
<table>
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<td>.21102257E-03</td>
<td>.49246632E-03</td>
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<td>6</td>
<td>.18862205E-02</td>
<td>.32833366E-02</td>
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<td>.29218184E-01</td>
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</tr>
<tr>
<td>16</td>
<td>0.</td>
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</table>
FILTER PARAMETERS
NFILT = 127 FP = \(0.00500\) TBWID = \(0.01541\) DP = \(0.01000\) DS = \(0.01000\)
FILTER COEFFICIENTS
1 \(-.57611818E-02\) \(-.14458869E-02\) \(-.15779811E-02\) \(-.17054889E-02\)
6 \(-.18272702E-02\) \(-.2044951E-02\) \(-.21345667E-02\) \(-.22110148E-02\)
11 \(-.22685610E-02\) \(-.23235239E-02\) \(-.23165943E-02\) \(-.22818637E-02\)
16 \(-.22201999E-02\) \(-.20019212E-02\) \(-.18400413E-02\) \(-.16423613E-02\)
21 \(-.14040333E-02\) \(-.80807552E-03\) \(-.45054632E-03\) \(-.49315302E-04\)
26 \(.39177683E-03\) \(.88090117E-03\) \(.1420564E-02\) \(.19883328E-02\)
31 \(.32498950E-02\) \(.39438586E-02\) \(.46685324E-02\) \(.54340488E-02\)
36 \(.70536956E-02\) \(.79036343E-02\) \(.87797060E-02\) \(.96719531E-02\)
41 \(.11502901E-01\) \(.12431251E-01\) \(.13361246E-01\) \(.14291479E-01\)
46 \(.16127318E-01\) \(.17902958E-01\) \(.18750877E-01\) \(.19572419E-01\)
51 \(.20359358E-01\) \(.21108628E-01\) \(.21814687E-01\) \(.22474542E-01\)
56 \(.23637514E-01\) \(.24135636E-01\) \(.24573834E-01\) \(.24947050E-01\)
61 \(.25501145E-01\) \(.25673888E-01\) \(.25780396E-01\) \(.25814786E-01\)

PLOTTING IN SUBROUTINE CALCZ

"MDAT, NDAT" PAIRS - 2 1
SPECIAL COORDINATES 20.590 0.000
PLOT LIMITS - 1160 2359 -9.0000 2.9900
(0)MS(1) (0)CM(1)
PLOT SCALES - -.90000E+01 .26257E+72 .29900E+01 -.41374E-01 .26257E+72 -.20370E-01

"MDAT, NDAT" PAIRS - 2 2
SPECIAL COORDINATES 20.590 0.000
PLOT LIMITS - 1160 2359 -9.0000 2.9900
(0)MS(1) (0)CM(1)
PLOT SCALES - -.90000E+01 .26257E+72 .29900E+01 -.95515E-01 .26257E+72 .12158E-02

"MDAT, NDAT" PAIRS - 2 1 2 2
SPECIAL COORDINATES 20.590 0.000 0.000 0.000
COORDINATES AT SHOT EJECTION - -.20370E-01 -.72367E-01
PLOT LIMITS - 1160 2359 -.0040 -.0095
(0)CM(1)
PLOT SCALES - -.20000E-01 .10000E-01 .20000E-01 -.20000E-01 .10000E-01 .20000E-01
"MDAT, NDAT" PAIRS - 3 1
SPECIAL COORDINATES   20.590    0.000
PLOT LIMITS - 1160 2359  -9.0000   2.9900
(0)MS(1)   (0)CM/MS(1)
PLOT SCALES - -.10000E+02   .20000E+01   .40000E+01   -.15000E-01   .50000E-02   .15000E-01

"MDAT, NDAT" PAIRS - 3 2
SPECIAL COORDINATES   20.590    0.000
PLOT LIMITS - 1160 2359  -9.0000   2.9900
(0)MS(1)   (0)CM/MS(1)
PLOT SCALES - -.90000E+01   .26257E+72   .29900E+01   -.56225E-01   .26257E+72   .39069E-01

"MDAT, NDAT" PAIRS - 3 1 3 2
COORDINATES AT SHOT EJECTION - -.12763E-02   -.28196E-01
PLOT LIMITS - 1960 2159   .0091   -.0032
(0)CM/MS(1)   (0)CM/MS(1)
PLOT SCALES - -.20000E-01   .10000E-01   .20000E-01   -.20000E-01   .10000E-01   .20000E-01

ZREF = -7.52000
"MDAT, NDAT" PAIRS - 6 2 2 1 2 2
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"MDAT, NDAT" PAIRS -  6  1
SPECIAL COORDINATES   20.590    0.000
PLOT LIMITS -  1960 2159   -1.0000   .9900
(0)MS(1)
PLOT SCALES -   -.10000E+01   .26257E+72   .99000E+00   -.53124E-03   .26257E+72   -.11726E-03

"MDAT, NDAT" PAIRS -  6  2
SPECIAL COORDINATES   20.590    0.000
PLOT LIMITS -  1960 2159   -1.0000   .9900
(0)MS(1)
PLOT SCALES -   -.10000E+01   .26257E+72   .99000E+00   -.31721E-02   .26257E+72   -.10128E-02

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SPECIAL COORDINATES   20.590    0.000
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PLOT LIMITS -  1960 2359   -.0004   -.0002
PLOT SCALES -   -.50000E-03   .50000E-03   .50000E-03   -.50000E-03   .50000E-03   .50000E-03
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WRITING ARRAY ON FILE - INDICES ARE   1  1   BRO512   1  1  BRL TUBE HOR

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"MDAT, NDAT" PAIRS -  2  1
SPECIAL COORDINATES   20.590    0.000
PLOT LIMITS -  1160 2359   -9.0000   2.9900
(0)MS(1)
(0)CM(1)
PLOT SCALES -   -.90000E+01   .26257E+72   .29900E+01   -.35949E-01   .26257E+72   -.19480E-01

"MDAT, NDAT" PAIRS -  2  2
SPECIAL COORDINATES   20.590    0.000
PLOT LIMITS -  1160 2359   -9.0000   2.9900
(0)MS(1)
(0)CM(1)
PLOT SCALES -   -.90000E+01   .26257E+72   .29900E+01   -.72686E-01   .26257E+72   .20543E-02
"MDAT, NDAT" PAIRS -  2  1  2  2  
SPECIAL COORDINATES   20.590    0.000    0.000    0.000
COORDINATES AT SHOT EJECTION -  -.19480E-01   -.53931E-01
PLOT LIMITS -  1160 2359  -.0023   -.0073

(0)CM(1)   (0)CM(1)
PLOT SCALES -  -.20000E-01   .10000E-01   .20000E-01   -.20000E-01   .10000E-01   .20000E-01

"MDAT, NDAT" PAIRS - 3  1  
SPECIAL COORDINATES   20.590    0.000
PLOT LIMITS -  1160 2359  -.90000   2.9900

(0)MS(1)   (0)CM/MS(1)
PLOT SCALES -  -.10000E+02   .20000E+01   .40000E+01   -.15000E-01   .50000E-02   .15000E-01

"MDAT, NDAT" PAIRS -  3  2  
SPECIAL COORDINATES   20.590    0.000
PLOT LIMITS -  1160 2359  -.90000   2.9900

(0)MS(1)   (0)CM/MS(1)
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COORDINATES AT SHOT EJECTION -  -.19140E-02   -.22433E-01
PLOT LIMITS -  1960 2159  .0063   -.0027

(0)CM/MS(1)   (0)CM/MS(1)
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APPENDIX D

D.2.6. Sample Plotted Output

These plots (Figures D.1 through D.25) are representative of the ones available from the program. In Figures D.1 through D.5, the solid line refers to the data from sensor 1 while the dashed line refers to the extrapolation of the data from sensors 2 and 3 to the position of sensor 1.
Figure D.1. Horizontal Displacement, cm.

Figure D.2. Vertical Displacement, cm.

Figure D.3. Magnitude, cm.

Figure D.4. Phase Angle, deg.
Figure D.5. X-Y Plot Of Displacement, cm

Figure D.6. X-Y Plot Of Sensor 1 Displacement, cm

Figure D.7. X-Y Plot Of Sensor 1 Displacement, Amplitude Zeroed At Time Of Shot Ejection
Figure D.8. $e'_{31}$ At ZREF = .0

Figure D.9. $e'_{32}$ At ZREF = .0

Figure D.10. X-Y Plot Of $e'_{31}$ And $e'_{32}$ At ZREF = 0
Figure D.11. Horizontal Displacement At ZREF = .0, cm

Figure D.12. Vertical Displacement At ZREF = .0, cm

Figure D.13. X-Y Plot Of Displacement At ZREF = .0, cm
Figure D.14. Horizontal Velocity At ZREF = .0, cm/ms

Figure D.15. Vertical Velocity At ZREF = .0, cm/ms

Figure D.16. X-Y Plot Of Velocity At ZREF = .0, cm/ms
Figure D.17. $e'_{31}$ At $Z_{REF} = -7.524$ cm

Figure D.18. $e'_{32}$ At $Z_{REF} = -7.524$ cm

Figure D.19. X-Y Plot Of $e'_{31}$ And $e'_{32}$ At $Z_{REF} = -7.524$ cm
Figure D.20. Horizontal Displacement At ZREF
= - 7.524 cm

Figure D.21. Vertical Displacement At ZREF
= - 7.524 cm

Figure D.22. X-Y Plot Of Displacement AT ZREF = - 7.524 cm
Figure D.23. $e'_{31}$ At ZREF = - 7.524 cm

Figure D.24. $e'_{32}$ At ZREF = - 7.524 cm

Figure D.25. X-Y Plot Of $e'_{31}$ And $e'_{32}$ At ZREF = - 7.524 cm
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**Aberdeen Proving Ground**

- Dir, USAMSAA
  - ATTN: AMXSY-D
  - AMXSY-MP, H. Cohen
  - AMXSY-G, E. Christman
  - AMXSY-OSD, H. Burke
  - AMXSY-G, R.C. Conroy
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- Cdr, USATECOM
  - ATTN: AMSTE-TO-F

- Cdr, CRDC, AMCCOM
  - ATTN: SMCCCR-RSP-A
  - SMCCCR-MU
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- Dir, USAHEL
  - ATTN: A.H. Eckles, III

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4. How specifically, is the report being used? (Information source, design data, procedure, source of ideas, etc.) __________________________________________________________

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