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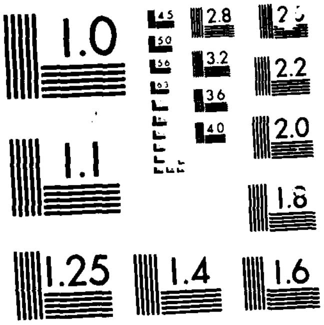

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TECHNICAL REPORT ARCCB-TR-86002

CORROBORATIVE MEASUREMENTS OF THE TRANSVERSE MOTION OF A GUN TUBE DURING FIRING

T. E. SIMKINS
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R. D. SCANLON

JANUARY 1986

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
CLOSE COMBAT ARMAMENTS CENTER
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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This work presents new measurements of transverse motion of the 30 mm (GAU-8) gun tube first reported at the Third Gun Dynamics Symposium in 1982. The measurements are unique and fully corroborated through the use of two independent measuring devices. In particular, the work discusses three items of interest. First, there definitely exists a 'base-line' transverse tube movement, the cause of which has yet to be determined. The magnitude of this

(CONT'D ON REVERSE)

20. ABSTRACT (CONT'D)

motion is of the same order as that due to other causes intentionally introduced for study. Second, intentionally introducing an eccentric breech mass produces muzzle displacements in good agreement with theoretical models, provided the 'base-line' component is accounted for. Finally, the muzzle rotation created by the moving projectile - though insignificant when operating alone - is strongly coupled to, and capable of greatly modifying the rotation due to other causes. This coupling does not appear to strongly affect muzzle displacement. It is concluded that predictions from gun dynamics models which agree well with displacement measurements, may err greatly when used to predict muzzle rotation, the quantity of which is of central interest.

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INTRODUCTION

The work herein reports further measurements of the transverse muzzle motion of an elastically suspended 30 mm gun tube. When last reported (ref 1), there were significant but unexplained muzzle movements prior to shot ejection. As a result, the credibility of the measurements of these motions was brought into question and it was decided that further analysis could not be justified until fully corroborated measurements were in hand. It was decided that two completely independent methods of measuring muzzle displacement would be employed simultaneously and that close agreement of these measurements would be demanded for acceptability. This quest for corroborated - and hence believable - measurements was highly successful as the results herein will demonstrate.

Having the proper instrumentation and measurement techniques in hand, however, did not guarantee immediate success in totally explaining the motions of the 30 mm tube during firing - the central problem of gun dynamics to which we have finally been able to return. Latest measurements, although greatly improved from those reported in 1982 (ref 1), still reveal an unexplained transverse movement of the tube prior to shot ejection. Furthermore, the magnitude of this motion is roughly the same as that which is to be studied from intentional causes such as tube curvature, tube and/or projectile eccentricity, etc. There can be little doubt that the cause of this underlying motion will be found, but as yet this is not the case.

---

[1] Simkins, T. E., Scanlon, R. D., and Benedict, R., "Transverse Motion of an Elastically Supported 30 mm Gun Tube During Firing," Proceedings of the Third U.S. Army Symposium on Gun Dynamics, ARLCB-SP-82005, Vol. I, May 1982, pp. I-72 - I-95.

EXPERIMENTAL DESIGN AND INSTRUMENTATION

Referring to Figure 1, the 30 mm/GAU-8 gun tube was suspended as described in Reference 1. Briefly, the tube is suspended by two pairs of wires from a virtually rigid overhead structure. The wires are 0.026 inch in diameter and each is approximately 50 inches in length. The recoiling tube thus behaves as an elastic bar-pendulum, stretching each wire approximately 0.010 inch at shot ejection. A NASTRAN model of this means of support indicates that the wire support loads create negligible transverse tube motion prior to shot ejection, i.e., that the suspension as modeled can be regarded as 'soft.' Following shot ejection, the recoil motion is arrested by contact between a circular buffer plate attached to the breech and a block of open-cell silica foam. (This foam has been found far superior to the 'styrafoam' used previously.)

The propellant charge used in these experiments is half that normally used in a standard GAU-8 round and yields a maximum pressure of about 10,000 psi. The round is separated from its case and manually started into the origin of rifling with a light tap. The cartridge case containing the propellant is then inserted and forced home as the threaded breech cap is tightened. The breech cap contains a small central recess into which an electrically actuated, propellant-driven firing pin is inserted.*

---

[1] Simkins, T. E., Scanlon, R. D., and Benedict, R., "Transverse Motion of an Elastically Supported 30 mm Gun Tube During Firing," Proceedings of the Third U.S. Army Symposium on Gun Dynamics, ARLCB-SP-82005, Vol. I, May 1982, pp. I-72 - I-95.

*These 'mini-actuators' are manufactured by ICI Americas, Inc., Atlas Aerospace Division, P.O. Box 819, Valley Forge, PA.

Instrumentation used to perform the measurements presented herein consists of two late model optical trackers (trade name - 'Optron'), and one so-called 'eddy probe' manufactured by Dymac Division of Scientific-Atlanta. One Optron is used with a light source which is interrupted as the shot leaves the muzzle. This, plus a breakwire mounted across the muzzle provides two independent measurements of the time of shot ejection. Agreement between the two is within 0.0002 second. It is hoped that in the future an inductance device will improve this measurement. The remaining Optron is used to record the vertical motion of the tube approximately six inches rearward of the muzzle. From this point the muzzle protrudes into a tube which exits through a wall of the room. The tube protects the instrumentation from muzzle flash and smoke. The end of this tube also serves as a mounting place for the eddy probe which is positioned 0.050 inch directly over the point of the tube being followed by the tracker. Thus the tracker and the eddy probe both follow the motion of the same point on the upper surface of the tube at all times. Owing to recoil, of course, different material surface points are being tracked in time, i.e., the measurement frame is Eulerian, not Lagrangian. This difference is of little consequence for the purpose at hand, however.

Measurements are monitored and recorded digitally on a four-channel Nicolet system. Approximately twenty milliseconds of data are recorded from each round using the muzzle breakwire and a trigger.

MEASUREMENTS OF GUN TUBE MOTION

Figure 2 shows the motion of the muzzle as measured by an optical tracker and by the eddy probe. Shot ejection is taken at t = 0.0. It is estimated that most of the time agreement is within 0.0002 inch (0.2 mils). Assuming sufficient care is taken to duplicate all of the preliminaries, a second shot will produce measurements in close agreement with those of the first shot. This is exemplified in Figure 3.

Presently there is no explanation as to the cause of the motions depicted in Figures 2 and 3, i.e., no eccentric masses have been applied to the tube, and the curvature of the tube 'as manufactured' is not sufficient (according to our two computer models) to create motion of this magnitude. Likewise, the support reactions applied by the wires are not supposed to change radically during recoil. (A thorough check of these reaction forces is presently underway.)

Figure 4 shows the displacement of the muzzle when an eccentric mass is added to the breech end of the tube. The eccentric mass is created by simply replacing the 7.75 lb circular buffer plate with an identical one whose center is located below the central axis of the tube. The weight of the entire recoiling mass is 90.8 lbs. The eccentric location of the buffer plate is 1.3 inches directly below the bore axis of the tube. In Figure 5 the response shown in Figures 2 and 3 is taken as a 'base-line' and subtracted from that of Figure 4. The result is in reasonable agreement with that predicted by a NASTRAN model of the system. This is shown in Figure 6.

MODEL VALIDATION

The agreement shown in Figure 6 is at least as close as that in Figure 2, if one disregards the higher frequency components of the motion (probably radial vibrations); i.e., the experimental measurements and the NASTRAN-predicted muzzle displacements agree to the same extent as our measurement devices. It would appear, therefore, that we have a useful and validated computer model. Assuming this to be the case, one of the most expected uses of a computer model of a gun system is to predict muzzle rotation. It is of much more interest to know muzzle rotation than it is to know muzzle displacement, target error being associated most strongly with the former. Can our NASTRAN model be trusted to predict muzzle rotation? The answer is very negative. One reason for this will be shown - the fact that our NASTRAN model does not account for moving projectile mass. Unfortunately, there may be others.

In Figures 7a through 7d the predicted muzzle responses due to an eccentric breech mass with and without the presence of the moving projectile mass are compared. (These predictions were produced by a second computer code in which moving mass effects are easier to include.) It is observed that although there is close agreement between muzzle displacement predictions with and without moving mass effects, the predictions of the (all-important) muzzle rotations are totally different. Thus the effect of moving projectile mass cannot be ignored.

While it has been shown that moving projectile mass must be included in any mathematical model from which muzzle rotation predictions are expected, this is by no means a sufficient condition. Other effects normally overlooked and expected to be negligible, may have to be included also. Most important, one may not know what they are, or in what detail to describe them. For example, the muzzle rotation predicted when the moving projectile is included may well depend on the detail with which it is modeled. (In Figures 7c and

7d, the projectile was simply modeled as a moving point mass.) It may be concluded, therefore, that the only way to be certain that a model can be trusted to predict muzzle rotations is by experimental verification - the very task one hoped to avoid! In conclusion, complete model validation requires measurement of displacement and rotation.

That the inclusion of moving projectile mass in any mathematical model of a gun system would have such a dramatic effect on predicting muzzle rotations may come as a surprise to some investigators. After all, predictions of muzzle motion due to a moving projectile mass in the absence of other load functions (such as eccentric breech mass, support reactions, curvature, etc.) have been virtually negligible. One must not forget, however, that the tube response due to combinations of load functions which are motion-dependent, is not simply the sum of the responses due to each load acting independently. Even though one is dealing in general with a linear model based on some particular linear partial differential equation (p.d.e.), the differential operator is altered every time a motion-dependent load is included or excluded. The operator must remain the same in order for linear superposition to hold. For example, consider the partial differential equations corresponding to Figures 7a through 7d. If the moving projectile mass and an eccentric breech mass are both included, the p.d.e. is

$$(EIy'')'' + \rho\ddot{y} = \varepsilon M\alpha(t)\delta'(x) - m_p(\ddot{y}+2\dot{y}'\dot{\xi}+\dot{\xi}^2y''+g)\,\delta(x-\xi) \qquad (1)$$

where $\alpha(t)$ is the recoil acceleration of a breech mass M located distance ε from the bore axis (see Figure 7a), m_p is the mass of the projectile located at a distance $\xi(t)$ from the breech end of the tube, y is the transverse displacement of the tube, δ is the Dirac function, and g is the gravitational constant. Note that the projectile mass creates a motion-dependent load function - it depends on y and its derivatives. The solution to Eq. (1) at the muzzle is shown in Figures 7a and 7b.

On the other hand, if the moving projectile is neglected

$$(EIy'')'' + \rho\ddot{y} = \epsilon M\alpha(t)\delta'(x) \qquad (2)$$

and the solution is shown in Figures 7c and d. A quick glance shows that the displacement is hardly changed from Figure 7a, but the rotation (y') is completely different.

Now consider the case where the moving projectile is the only load acting). The p.d.e. is

$$(EIy'')'' + \rho\ddot{y} = -m_p(\ddot{y}+2\dot{y}'+\dot{\xi}^2y''+g)\,\delta(x-\xi) \qquad (3)$$

The muzzle displacement and rotation corresponding to this equation are shown in Figure 8. As can be seen, their magnitudes are very small. If these are added to those from Eq. (2), hardly any change to Figures 7c and 7d would result, demonstrating that solutions to Eqs. (2) and (3) cannot be summed to yield the solution to Eq. (1). This is shown in Figure 9. In effect, the motion-dependent term affects the operator of the p.d.e. and one cannot add solutions to equations with different operators.

CONCLUSION

1. The measurement of transverse tube displacements during firing can now be accomplished with a high degree of confidence. Eddy probes and optical trackers may be expected to disagree as much as 0.0005 inch (0.0127 mm). Neither device can be assumed superior to the other, but eddy probes are

relatively inexpensive - almost expendable, and very easy to use by comparison.

2. There is no way to know if all motion-dependent load functions have been accounted for in a given mathematical model or if those which have been accounted for have been described in sufficient detail. It has been shown herein that motion-dependent load functions, which are unimportant when acting alone, become very important when acting in concert with other loads. The importance of such motion-dependent loads cannot be assessed from their effects on tube displacement which may be minimal. Tube rotation, however, may depend significantly on the inclusion and proper description of these loads. Thus, a model should not be considered validated until displacement and rotation have been verified experimentally. Needless to say, all models must be validated to be of any use. In view of this, it is important to the future of analytical gun dynamics that means be found to obtain measurements of tube rotations - particularly at the muzzle. In addition, such measurements should be corroborated.

REFERENCES

1. Simkins, T. E., Scanlon, R. D., and Benedict, R., "Transverse Motion of an Elastically Supported 30 mm Gun Tube During Firing," Proceedings of the Third U.S. Army Symposium on Gun Dynamics, ARLCB-SP-82005, Vol. I, May 1982, pp. I-72 - I-95.

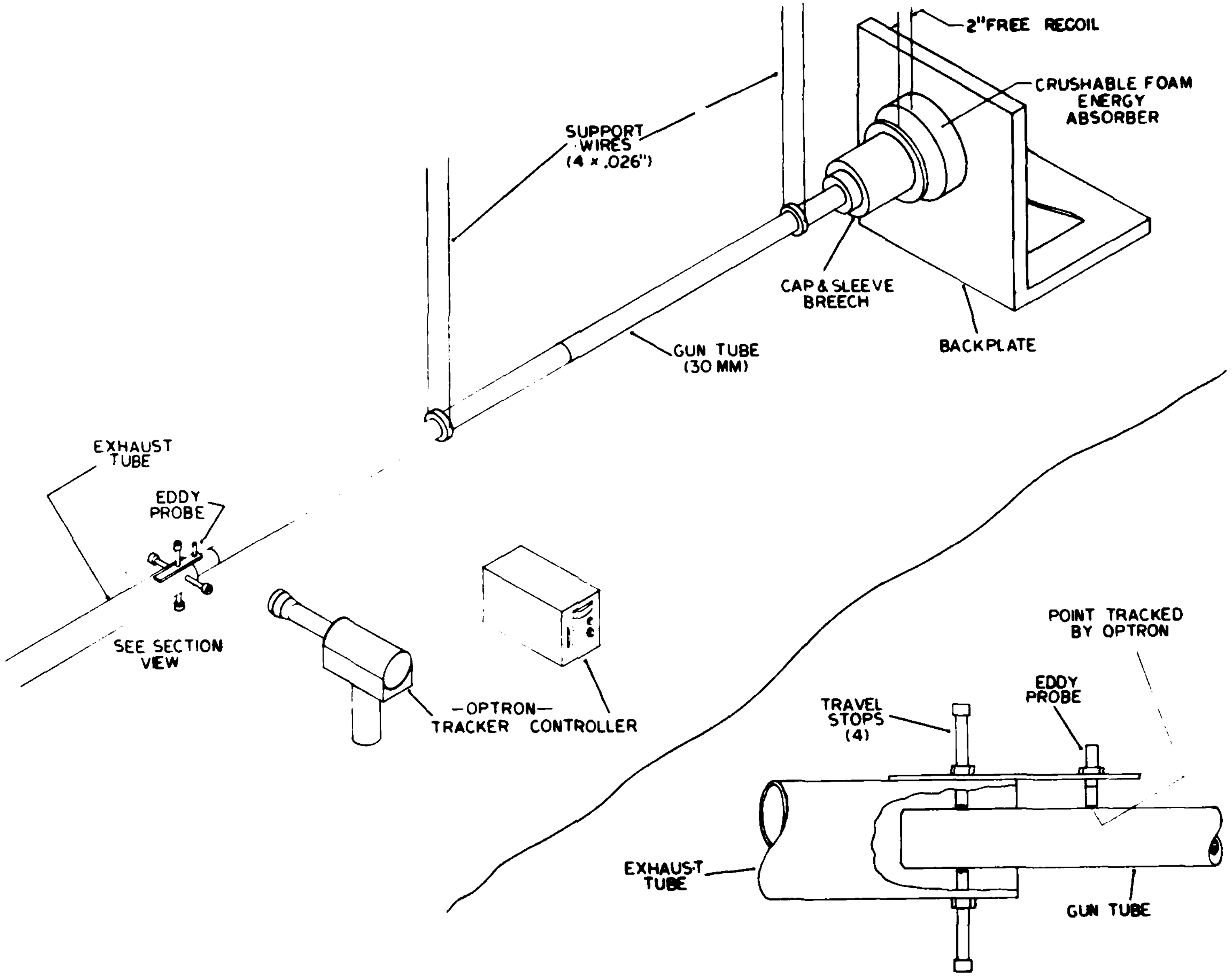

Figure 1. Elastically suspended 30 mm gun system.

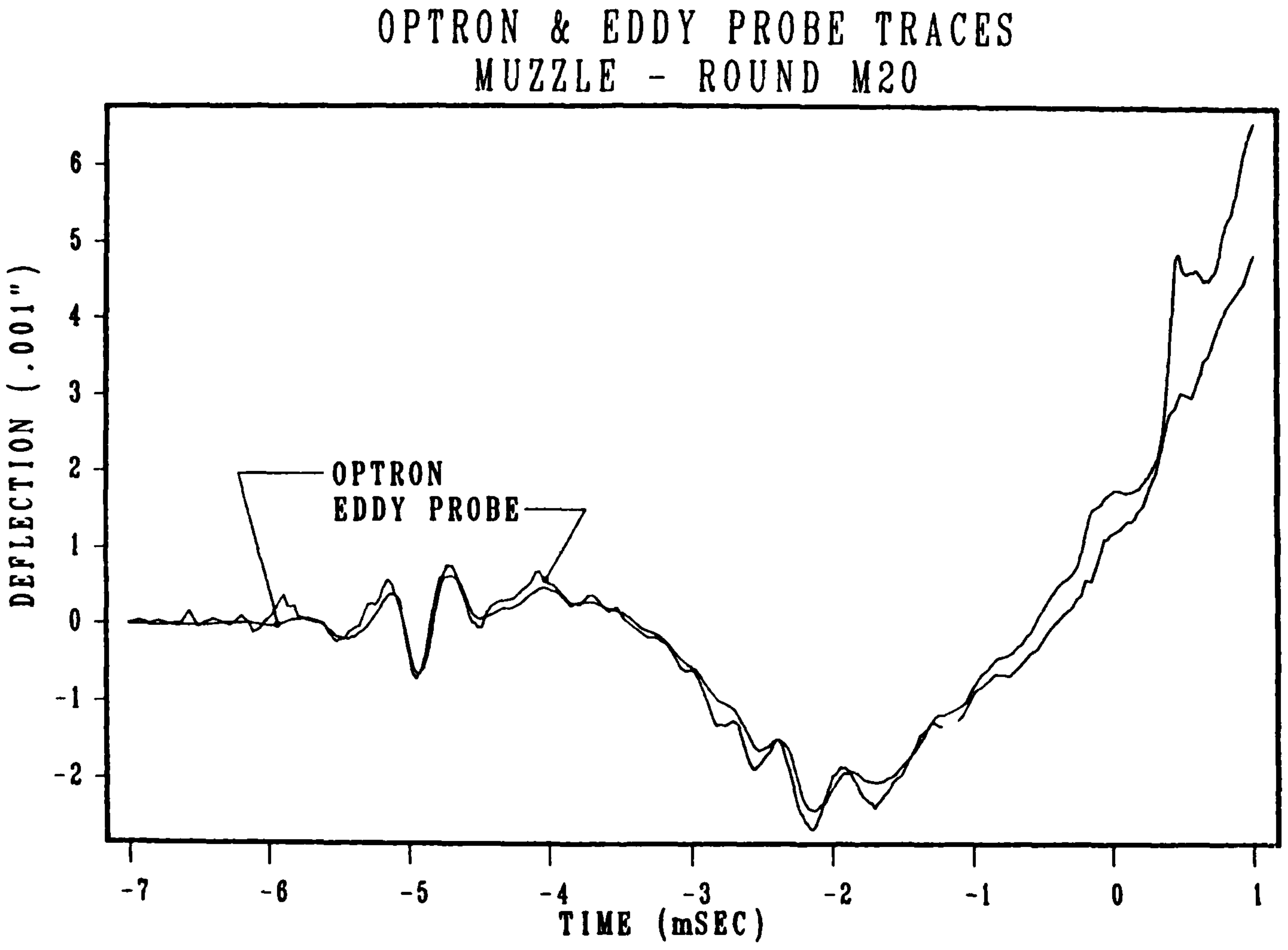
OPTRON & EDDY PROBE TRACES
MUZZLE - ROUND M20
OPTRON
EDDY PROBE
DEFLECTION (.001")
6
5
4
3
2
1
0
-1
-2
-7
-6
-5
-4
-3
-2
-1
0
1
TIME (mSEC)

Figure 2

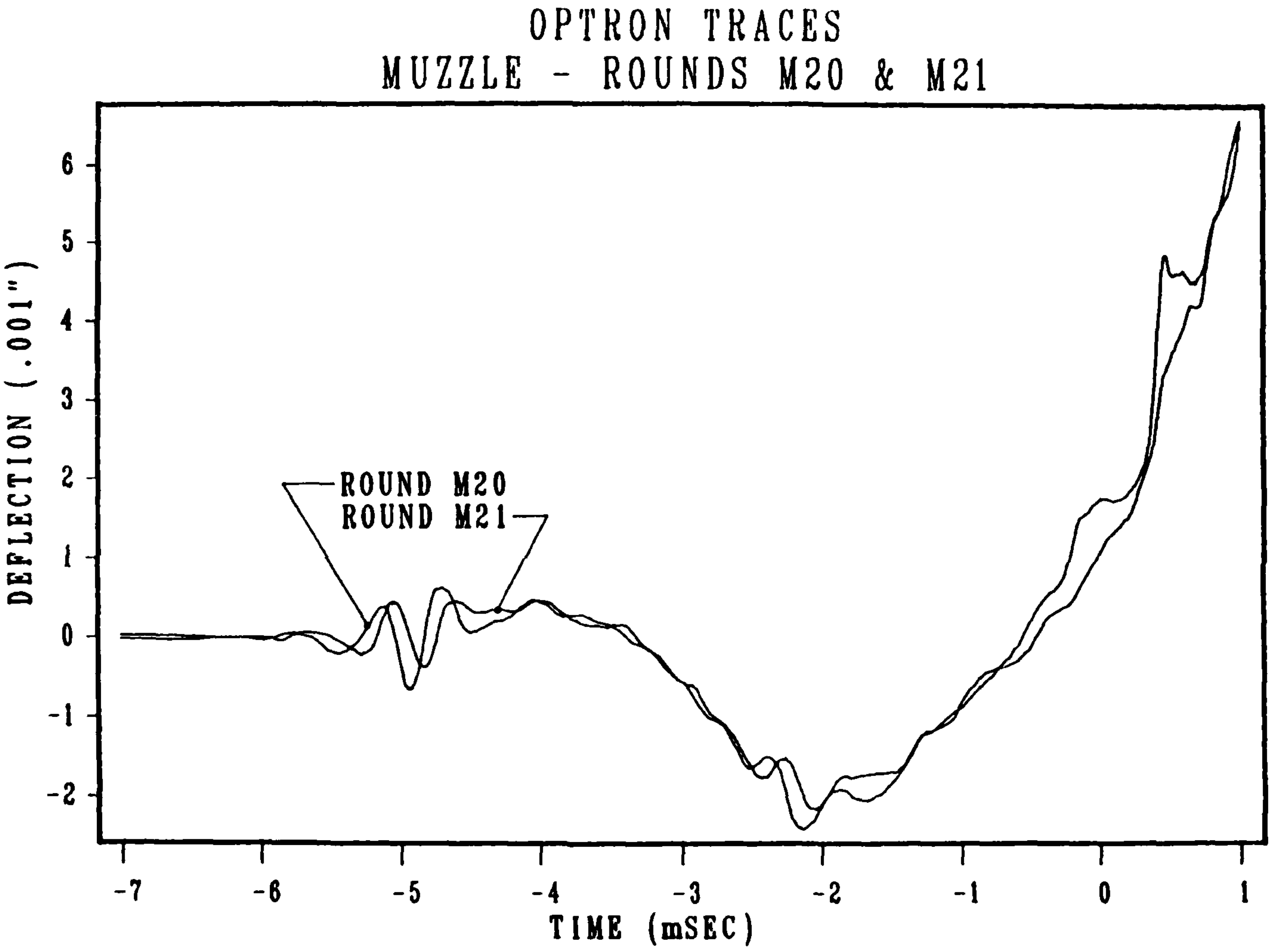
OPTRON TRACES
MUZZLE - ROUNDS M20 & M21

Figure 3

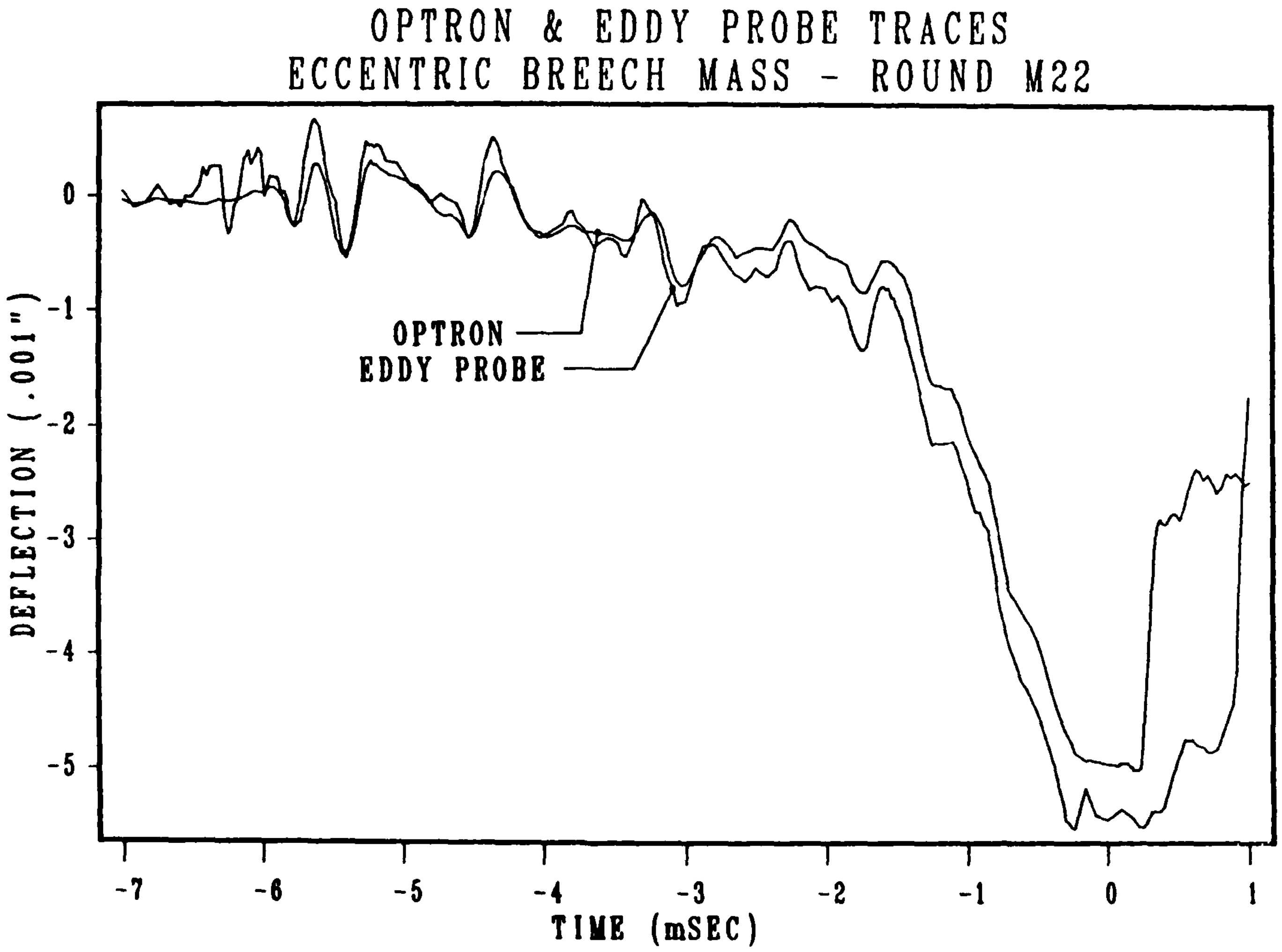
OPTRON & EDDY PROBE TRACES
ECCENTRIC BREECH MASS - ROUND M22
DEFLECTION (.001")
0
-1
-2
-3
-4
-5
OPTRON
EDDY PROBE
-7
-6
-5
-4
-3
-2
-1
0
1
TIME (mSEC)

Figure 4

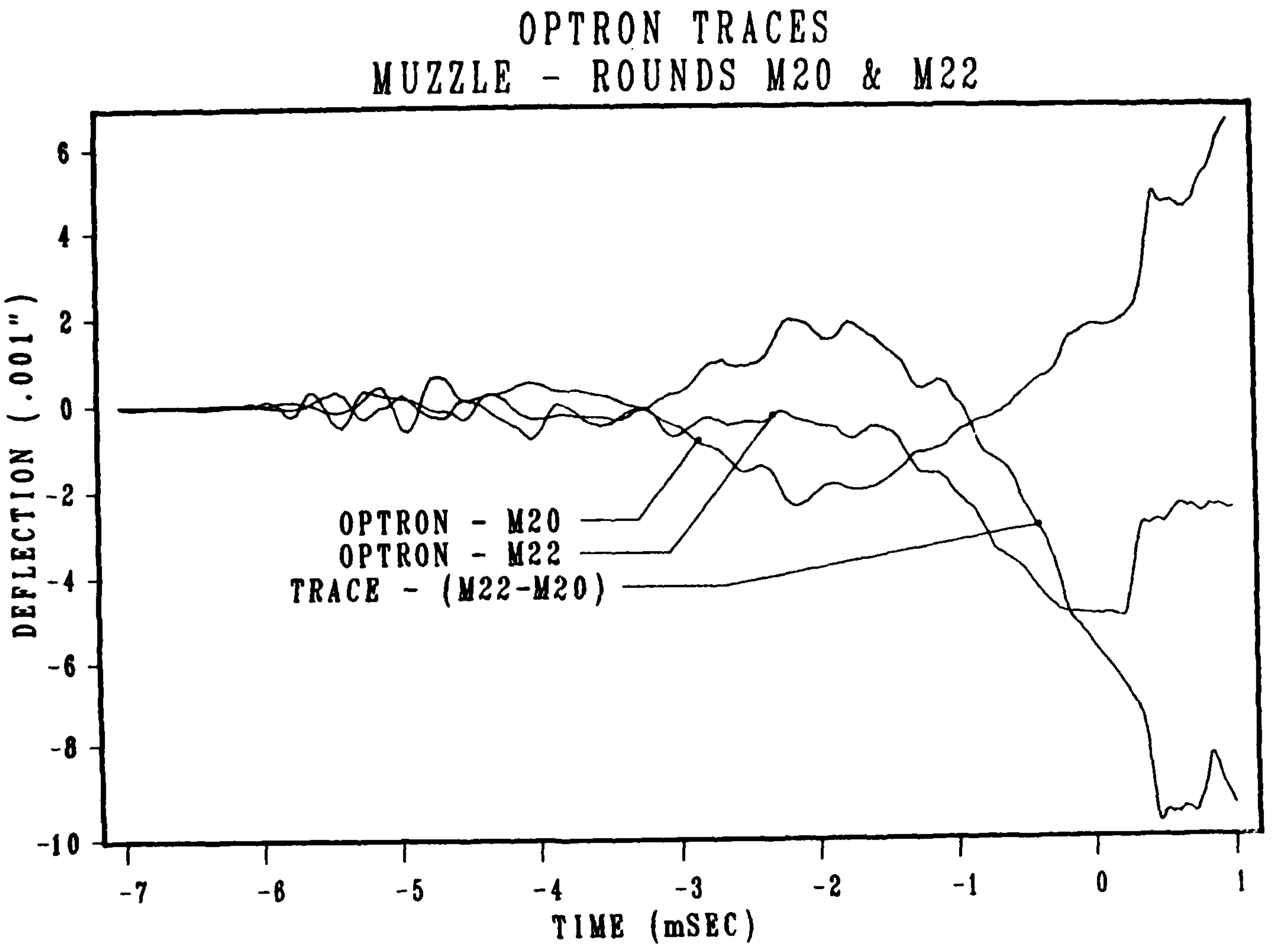
OPTRON TRACES
MUZZLE - ROUNDS M20 & M22
DEFLECTION (.001")
6
4
2
0
-2
-4
-6
-8
-10
OPTRON - M20
OPTRON - M22
TRACE - (M22-M20)
-7
-6
-5
-4
-3
-2
-1
0
1
TIME (mSEC)

Figure 5

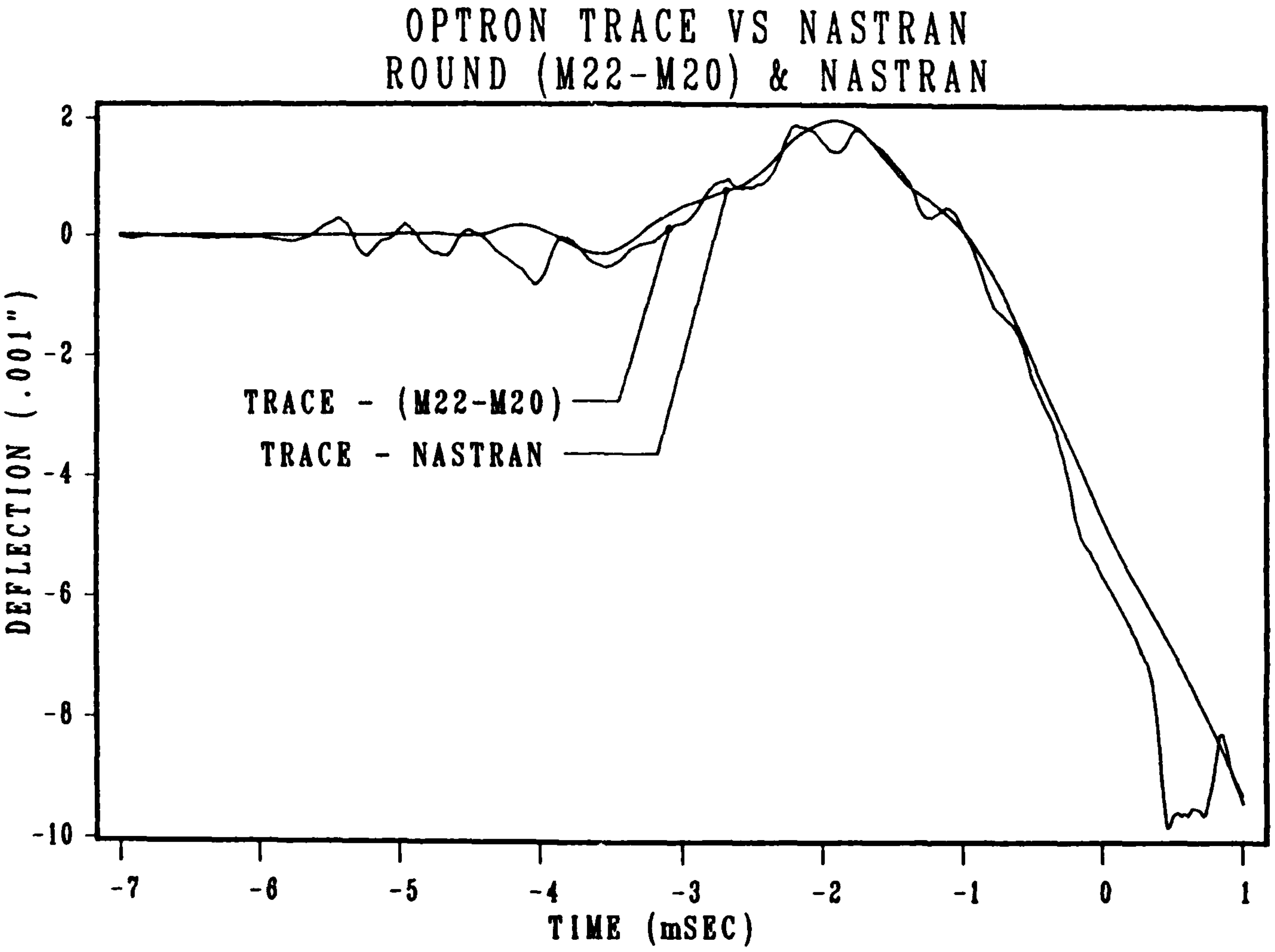
OPTRON TRACE VS NASTRAN
ROUND (M22-M20) & NASTRAN
TRACE - (M22-M20)
TRACE - NASTRAN
DEFLECTION (.001")
2
0
-2
-4
-6
-8
-10
TIME (mSEC)
-7
-6
-5
-4
-3
-2
-1
0
1

Figure 6

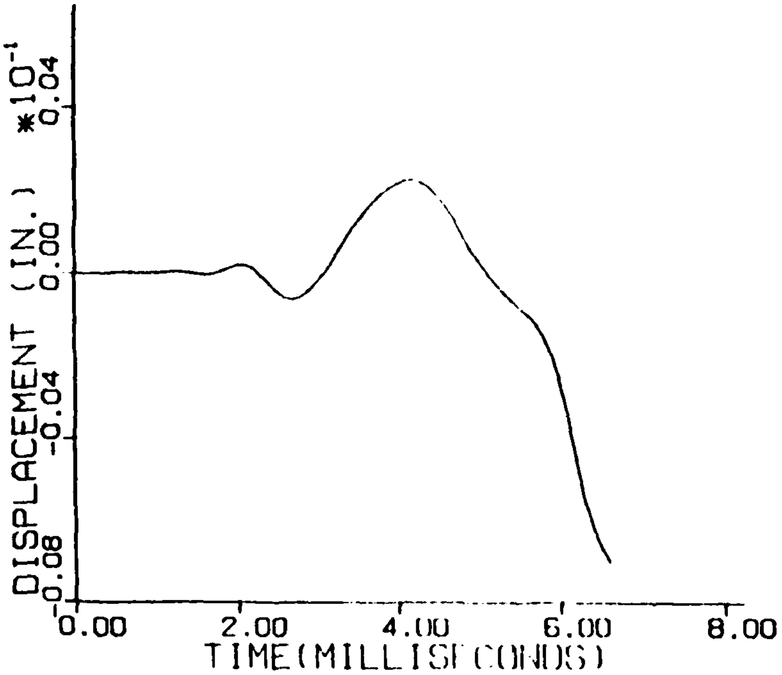

Figure 7a. Muzzle Displacement Due to Eccentric Breech Mass and Moving Projectile.

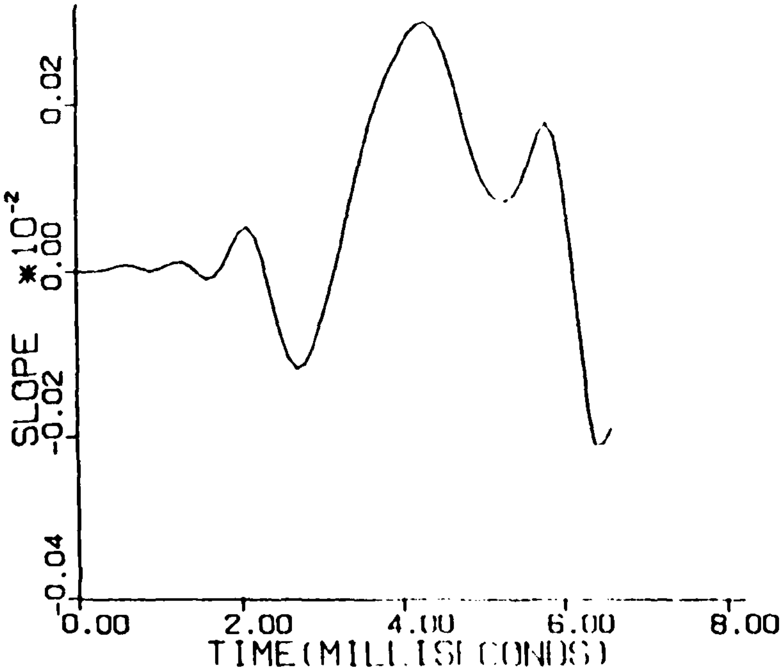

Figure 7b. Muzzle Rotation Due to Eccentric Breech Mass and Moving Projectile.

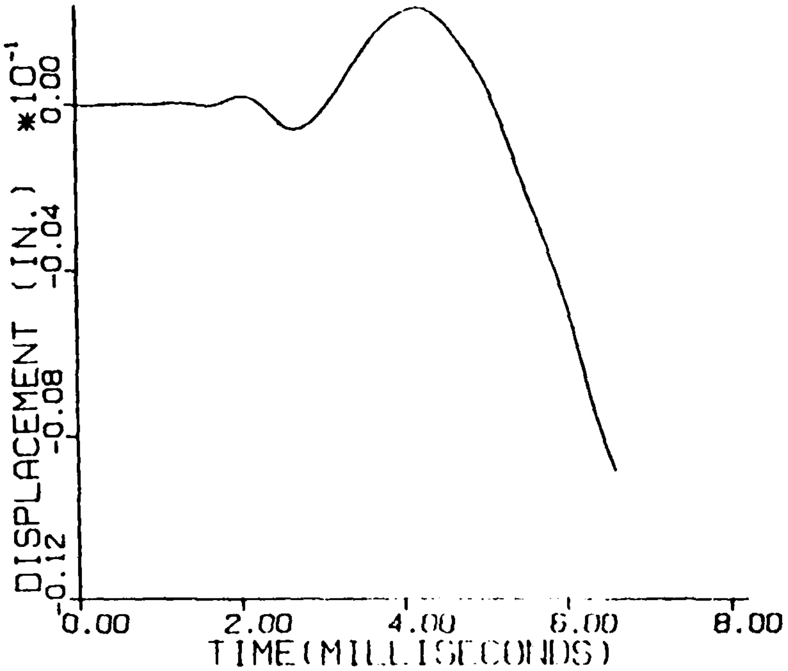

Figure 7c. Muzzle Displacement Due to Eccentric Breech Mass.

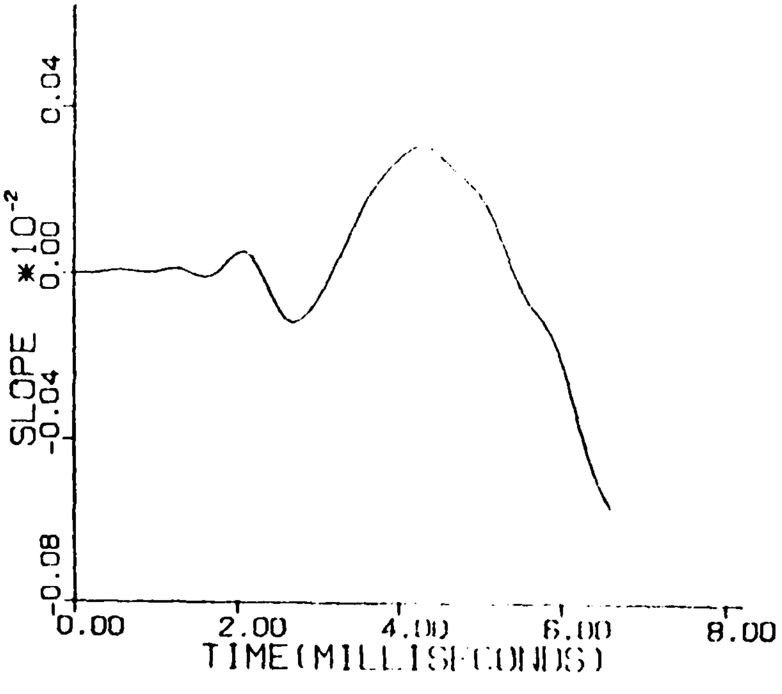

Figure 7d. Muzzle Rotation Due to Eccentric Breech Mass.

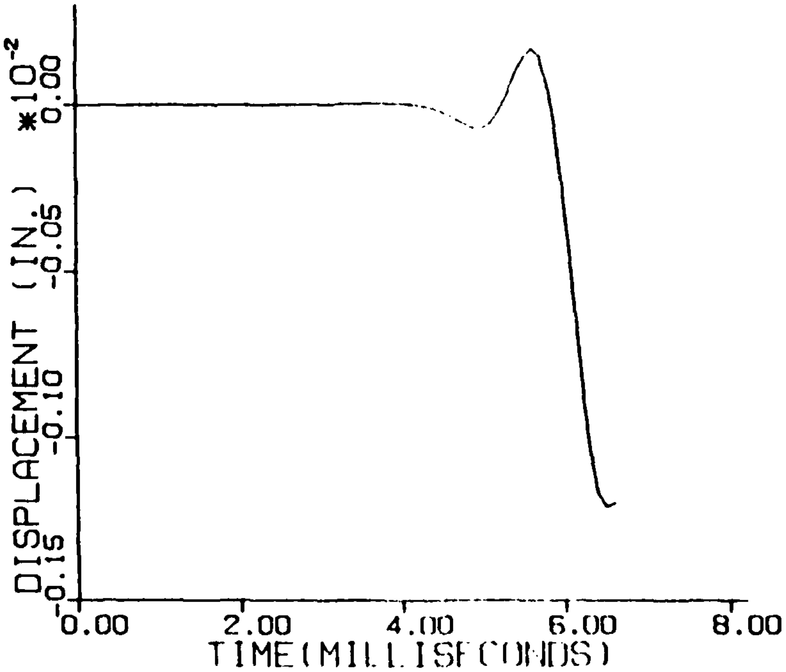

Figure 8a. Muzzle Displacement Due to Moving Projectile.

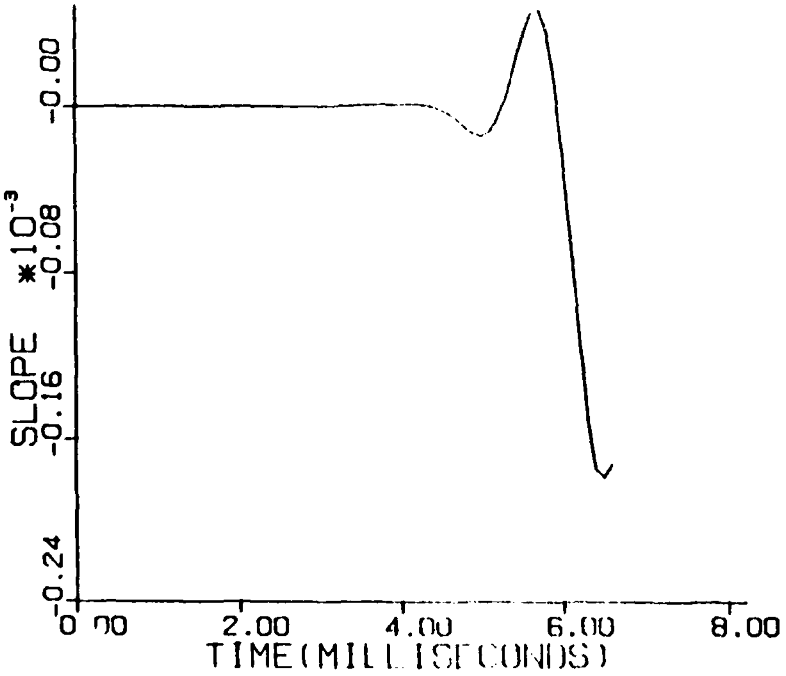

Figure 8b. Muzzle Rotation Due to Moving Projectile.

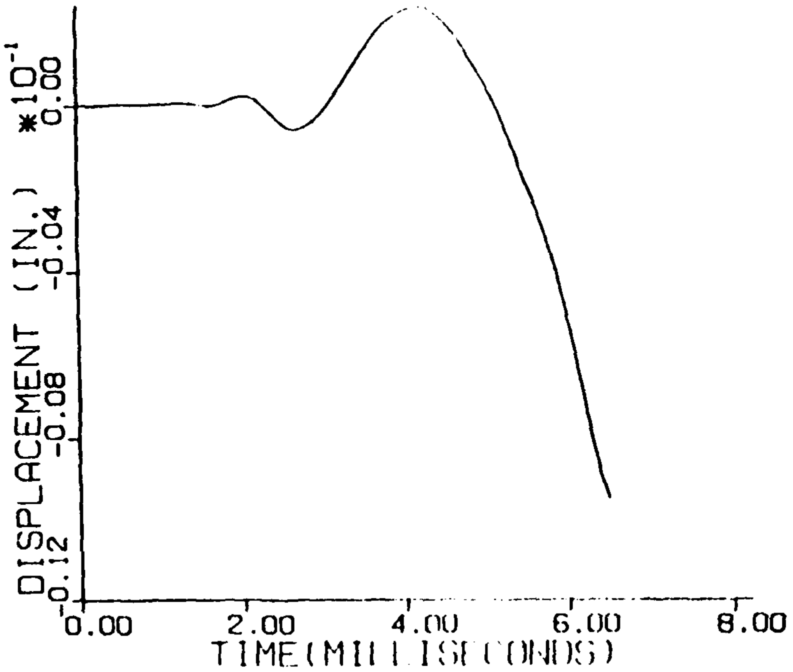

Figure 9a. Sum of Figures 7c and 8a.

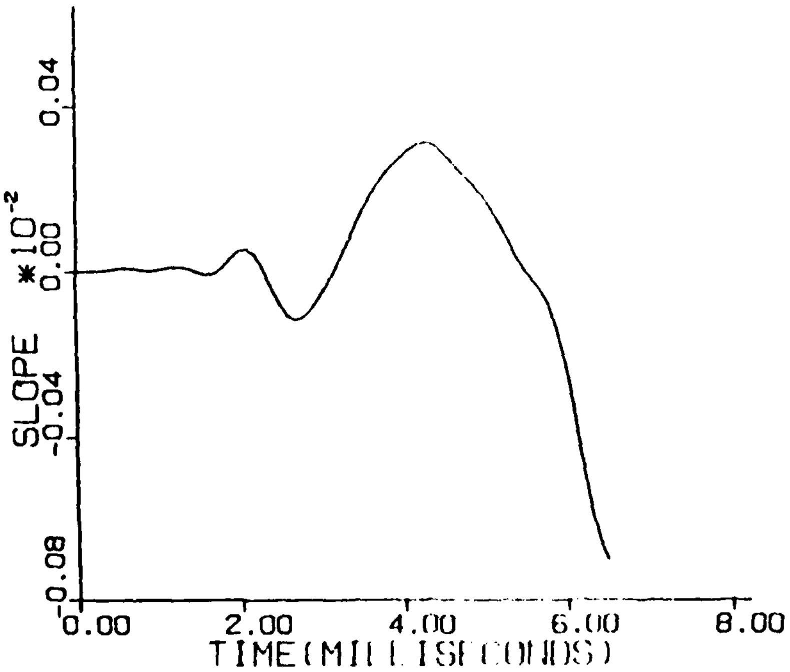

Figure 9b. Sum of Figures 7d and 8b.

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