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ASSESSMENT OF HOLLOW (TUBULAR) PROJECTILE TIME OF FLIGHT ON VULCAN AIR DEFENSE SYSTEM (VADS) ACCURACY

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Man in the loop experiments, utilizing the Vulcan Air Defense System Dynamic Field Evaluator (VADS-DFE), were conducted to assess VADS accuracy with standard M246 and reduced time of flight hollow (tubular) ammunition. Simulated targets flying linear flight paths with velocity over crossing range (V/R) ratios of 0.33 rad/s, 0.66 rad/s and 0.99 rad/s were utilized. Time histories of weapon pointing and tracking error were collected, reduced and analyzed. With hollow round ballistics employed in lieu of M246 ballistics, substantial improvements in weapon pointing accuracy were noted. Effects on tracking

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20. ABSTRACT (Continued)

accuracy, however, were small. In essence, standard Vulcan appears as a 24.0 mil system and Vulcan, with hollow ballistics, an 18.0 mil system for a net improvement of 27 percent. Tracking accuracy is hardly impacted (4 percent). Due to various experimental constraints, the results produced were inconclusive yet promising. It was therefore recommended that further development of hollow (tubular) ammunition continue for anti-aircraft warfare.

SUMMARY

This report concerns itself with the conduct of a non-firing demonstration study required to assess the operational effectiveness of the Vulcan Air Defense System while employing reduced Time of Flight hollow (tubular) ammunition and the standard M246 round.

A VADS with modified hollow round ballistics under the control of the Dynamic Field Evaluator provided a test facility wherein realistic simulated target images were generated and tracked by a trained gunner. Weapon pointing and tracking error time history records were collected for linear target flight paths whose velocity over range (V/R) ratios were 0.33 rad/s, 0.66 rad/s and 0.99 rad/s. Reduction and processing of these records, together with those obtained from Vulcan operating with Standard M246 and zero time of flight (sight caged) ballistics, permitted several comparisons.

Various constraints imposed the utilization of limited target parameters, such as one gunner, data reduction of one time history per V/R ratio and the hollow round's design goal ballistics. Since this was the case, the results contained herein are inconclusive; however, the overall assessment is that gains in gun system accuracy look promising with hollow ammunition and therefore its development should continue. Particular emphasis should be given to the determination of accurate hollow round ballistics, lethality against aircraft and ground targets, and its cost in production.

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FIGURES

INTRODUCTION

The objective of this test and demonstration effort was to make an assessment of the weapon pointing and tracking accuracy of the VADS, utilizing the M246 and hollow (tubular) round (figure 1)). Assessments utilizing mathematical models of the Vulcan have been made and reported upon by Meridith and Fournfelker (reference 1). The approach taken and described herein was to employ the Dynamic Field Evaluator (figures 2, 3 and 4) to exercise and monitor the performance of the actual weapon system. A VADS sight current generator (SCG) circuit card, modified to fit hollow round ballistics, was furnished by the Government (GFE). Changing the SCG output from the M246 round to the hollow round was done by replacing this board. It was expected that the hollow round sight current generator would improve overall system accuracy when employed in the Vulcan. This improvement would be due to the reduced time of flight of the projectile as compared to the M246 round. The reduced time of flight improves accuracy by reducing lead angle, the magnitude of which impacts fire control instrumentation errors.[1] Collected weapon pointing error test data have indicated this to be the case. It was also thought that larger optical-sight magnet currents would result from the reduced time of flight, and hence a situation approaching a caged sight condition would ease the gunner's burden and improve tracking accuracy. This hypothesis was never proven since tracking records for both rounds were essentially equivalent.

Lastly, because target acceleration errors are a function of time of flight, reduction of this error could not be witnessed since all the data collected was for constant velocity and constant altitude crossing courses.

[1]A theoretical sensitivity analysis utilizing the approach taken in reference 9 will demonstrate this to be true.

PRE-DEMONSTRATION WORK ACTIVITIES

BACKGROUND INFORMATION

A short discussion on the derivation of those functions involved in expressing the various angles, distances and rates of a target moving in a straight line at a constant velocity, altitude and cross-over range appears in reference 2. Knowing the complete time history of the target azimuth and elevation angles, plus the corresponding time history of range, the ideal gun coordinates (azimuth[2] and elevation of gun required to destroy the target) versus time are readily determined. Let the polar position of the target be defined by its azimuth, elevation and range at a particular time t. In order for a hit to occur at t, the gun must have been positioned at this azimuth and elevation at an earlier time $t - T_F$. The only problem is the determination of the time of flight (T_F) and the additional elevation required for gravity effects upon the round. With respect to the time of firing, $t - T_F$, the range value (Do(t)) is precisely future position range, D_p. Thus, at the firing instant, $D_p\ (t - T_F)$ equals Do(t). The problem of determining T_F given D_p and target elevation angle is a ballistics problem. In order to solve this problem a discussion of the ballistics fits for the 20 mm M246 and hollow (tubular) round follows.

BALLISTIC FITS

Table 1 was obtained from reference 3 and contains the hollow round ballistics for standard temperature and pressure (STP) at a 30° gun elevation. The ballistics were furnished to General Electric by DRDAR-ACW, Aberdeen Proving Ground, MD and were utilized by this contractor in the SCG circuit card design.

Firing range tests to ascertain the accuracy of these ballistics at 20°, 40° and 60° elevations have been made, but the results of these firings were not available for General Electric to

[2] Azimuth and train are used synonymously throughout this report to describe turret motion in and out of level or level situation.

utilize. Figure 5 is a comparison of firing test data for 40° elevation taken from reference 4 with theoretical 30° elevation data taken from table 1. The results of only three firings at 40° are shown. They are labelled as in reference 4, (8-1), (8-2) and (8-3).

Table 2 shows the slower M246 rounds ballistics for STP at 0° gun elevation. Before modification, the offline software appearing in reference 5 (appendix R) for the DFE had ballistic fits for this round in the following form,

$$R_E = D \{ 1 - 0.001\, e^{\left(\frac{D - 509}{369}\right)} \sin E_T \} \qquad D \lesssim 1217 \text{ meters}$$

$$R_E = D \{ 1 - 0.001\, e^{\left(\frac{D - 509}{369}\right)} \sin E_T \left(2.62 - 1.62 \frac{D}{1217}\right) \}$$

$$D \geq 1217 \text{ meters}$$

$$T_F = \frac{R_E}{V_M - K(V_M)} \qquad \text{FOR } R_E \; 500 \text{ meters} \lesssim 1400 \text{ meters}$$

$$T_F = 2.42757 + 0.355 \left(\frac{R_E - 1400}{100}\right) + 0.075 \left(\frac{R_E - 1700}{300}\right)^2$$

$$\text{FOR } R_E \geq 1400 \text{ meters}$$

$$Q = \frac{g T_F}{2 V_m} \left(\frac{V_m T_F + 2R_E}{3}\right) \qquad \text{FOR } R_E \lesssim 1400 \text{ meters}$$

$$Q = \frac{g T_F}{2 V_m} \left(\frac{V_m T_F + 2R_E}{3}\right) \left[1 + 0.19 \left(\frac{R_E - 1400}{1000}\right) \right]$$

$$\text{FOR } R_E \gtrsim 1400 \text{ meters}$$

where, R_E = Equivalent Ground Range

D = Slant Plane Range

E_T = Elevation of Target

T_F = Time of Flight

Q = Gravity Drop

The T_F fits were accurate to 3.64 milliseconds Root Mean Square (RMS) for all gun elevations between 0° and 90°. The fit error associated with gravity drop was negligible.

Since the SCG was designed around unvalidated 30° gun elevation ballistics, it was not necessary to employ the T_F fits shown above. In their place, a tenth order polynomial accurate to 0.383 milliseconds RMS was utilized. This polynomial is given by

$$T_F = a_o + a_1 D_p + a_2 D_p^{2} + a_3 D_p^{3} + \ldots \; a_{10} D_p^{10}$$

where, D_p = Future Position Slant Plane Range

a_o = 0.42399139D-04

a_1 = 0.71940072D-03

a_2 = 0.11233176D-05

a_3 = -0.57168055D-08

a_4 = 0.17296799D-10

a_5 = -0.29959931D-13

a_6 = 0.31577265D-16

a_7 = -0.20516763D-19

a_8 = 0.80030259D-23

a_9 = -0.17145130D-26

a_{10} = 0.15489013D-30

Examination of table 1 and figure 6 indicated an essentially flat trajectory out to a range of 2000 meters. Therefore a fit of the form $Q = b_o + b_1 D_p + b_2 D_p^2 + \ldots . b_n D_p^n$ was found to be appropriate for gravity drop.

OFFLINE SOFTWARE AND GENERATION OF TARGET TAPES

Next, the DFE offline software appearing in reference 5 (appendix S) was modified by incorporating the preceding ballistic expressions for the hollow round into its Fortran source. Insertion into the source was accomplished by utilizing the Data General Nova 1200 Editor. Once this was accomplished the Data General Compiler was employed to produce a final Fortran object tape from its modified source. With the modified source (hollow round) and original source, it was now possible to create punched paper target tapes with those flight path conditions given in table 3 and that linear geometry shown in figure 7. Reference 5 (appendix S) delineates the numerous steps that are required to generate these tapes. In essence, once the Fortran object program has been given the initial position, attitude and speed of the target, and a path specification in terms of yaw and pitch axis curvature over each of a maximum of 10 segments, the software computes position, attitude and speed of the target versus time. Based upon this information the ideal gun azimuth and elevation required for a hit are computed versus time. The outputs of this program are the initial target position and attitude, the time histories of target yaw rate, pitch rate and speed, and the time histories of the ideal gun azimuth and elevation angles. For the thirty second engagements utilized in this study, 3000 words of data were output on each punched paper target tape.

PRE-FLIGHT CHECKOUT OF DFE AND TARGET TAPES

A pre-flight checkout of all DFE and VADS equipment is required before the goodness of target tapes are ascertained and a gunner is trained and run for record. The procedures are well documented in reference 5 (appendices C, E, P and U), in which the following is described:

- Alignment of the DFE sight attachment to the VADS
- Measurement of Pitch and Roll of VADS
- Establishment of Initial Gun Line Position in Elevation
- DFE Sight Attachment Gyro Accuracy Test
- DFE Display Accuracy Test
- DFE Target Stability Test
- Temperature Compensation and Gyro Calibration
- A/D/A Converter Test
- Radar Target Simulator Test

A brief discussion of each test, portions of which have been excerpted from reference 5, follows.

ALIGNMENT OF THE DFE SIGHT ATTACHMENT TO THE VADS

It is necessary to align the center of the DFE CRT (Cathode Ray Tube) to the VADS sight reticle when the sight is in the electrically caged condition. This alignment assures that the datum for displaying sight lead angle and that for displaying target position to the gunner are coincident.

MEASUREMENT OF PITCH AND ROLL OF VADS

Measurement of pitch and roll is necessary to establish a reference from which the gun pointing error can be accurately measured. The gun pointing error is the difference between the ideal weapon position required to hit the target and the position of the weapon measured by the sight attachment gyro. The ideal weapon position is on punched paper tape and resides in the computer's memory after it is loaded into core.

ESTABLISHMENT OF INITIAL GUN LINE POSITION IN ELEVATION

Directly related to pitch and roll is the initial gun line position which must be accurately established so that the outputs of the sight attachment gyros can be accurately initialized for integration.

Normally, and within the constraints established by the effect of gunfire on pitch and roll, it should be necessary to establish the basic initial gun line only once during a series of target runs. Those values utilized for initial gun line elevation (E_{go}) are shown in table 3. It can be seen that the initial gun line elevation is equal to the initial elevation of the target (E_{To}) at time equal to zero. The flight path geometry in figure 7 shows these angles. After the basic initial gun line has been established, it is necessary to utilize the Vulcan Gunner's Quadrant to set the desired elevation for a given run. This is accomplished by first computing the setting, placing the setting into the quadrant and raising the mount using the hand controls to level the bubble on the quadrant. The elevation setting is equal to $(400 - E_{go}) - B$, where B = a small correction angle required to compensate for differences in the levelness of two adjacent sight attachment surfaces. For this demonstration B = -3.2 mils.

SIGHT ATTACHMENT GYRO ACCURACY TEST

The purpose of this test is to determine whether the DFE gyros and associated electronics can accurately measure gun turret motion. This is accomplished by noting the output of the DFE gyros as the turret is rotated through known separation angles.

DISPLAY ACCURACY TEST

The purpose of this test is to determine whether the DFE display and associated electronics can accurately stroke a given pattern on the face of its cathode ray tube. The DFE generates a CRT test pattern with index marks in elevation and train to allow measurements with the VADS azimuth indicator and Gunner's Quadrant to be compared with the display angles.

TARGET STABILITY TEST

During this test the DFE generates a target image. This image appears initially alongside the gunline. When the turret is rotated the target will remain fixed in space and will not be dragged along with the moving gun. The intent of this test is to measure the ability of the DFE to stabilize a target image in space. Such a capability, for example, is required to simulate a hovering helicopter.

TEMPERATURE COMPENSATION AND GYRO CALIBRATION TESTS

Large changes in ambient temperature can affect the normal calibration of the gyros and radar target simulator sufficiently that new scale factors should be entered in the On-Line assembly program to maintain the utmost accuracy. For this demonstration the temperature inside the gyro case was 30.6°C. The scale factors were as follows: Gyro AZ 45446, EL 46250, and RTS 436. This test determines the stability of the A/D - D/A converters, the accuracy to which they can transform a digital word to an analog signal, and an analog signal to its digital word.

RADAR TARGET SIMULATOR (RTS) TEST

The radar target simulator accuracy test compares the range generated by the RTS with the corresponding range voltage put out by the VADS VPS-2 radar. This test requires that an adjustable range value be transmitted from the Nova 1200 computer through the RTS to the VPS-2 radar where the output range voltage may be measured.

GUNNER TRAINING AND CHECKOUT OF TARGET TAPES

An engineering technician who never fired the VADS 20 mm cannon, but had some experience tracking DFE simulated targets, was utilized as the test subject. It was not known how well this subject had learned the tasks required of him. Since this was so, approximately four (4) hours of training were given to him. This was accomplished by having the subject track the three (3) flight paths whose conditions are shown in table 3. The target tapes generated for the demonstration were checked out at this point by ensuring that the VADS behaved properly with a gunner in the loop, that targets flew correctly and that data could be collected. Once it was determined that the tapes were satisfactory, training commenced in earnest.

The process of learning is a complicated one which is still not understood. However, it is known that learning to track targets with the VADS follows well defined curves such as that shown in figure 8. This curve shows how the subject improved his performance in a four (4) hour period. His learning was moderately rapid at the start and then leveled off asymptotically. It is possible that the level reached was not a true minimum but only a plateau. In that case, after further practice the possibility of asymptoting at a lower level could have occurred, however the subject felt that this was the best he could ever accomplish.

DEMONSTRATION WORK ACTIVITIES

RUN FOR RECORD WITH UNCAGED SIGHT

With the DFE and Vulcan checked out it was now possible to exercise the Vulcan with both hollow and M246 ballistics. The hollow round ballistics board was placed into the sight current generator, the gun elevation was initialized, a target for a V/R = 0.33 rad/s was put in full view of the gunner and centered on the sight attachment display.[3] The strip chart recorder was turned on by the DFE operator and a signal given to the gunner to close his action switch. The gunner commenced to acquire, radiate, track and after the Ready to Fire light lit, squeeze the trigger. The time histories shown in figure 9 were collected in real time while the subject performed. From the top down they are Elevation/Train Tracking Error (±25.0 mils full scale) and Elevation/Train Weapon Pointing Error (±100.0 mils full scale). Along the abscissa a major division is 2.0 seconds with each record lasting 30.0 seconds. The same routine was continued for V/R = 0.66 rad/s and V/R = 0.99 rad/s targets (figures 10 and 11). Once this was completed, the hollow round ballistics board was removed and replaced with the M246 board. Performance information on VADS was once again collected (figures 12 through 14) for targets with V/R = 0.33 rad/s, 0.66 rad/s and 0.99 rad/s.

RUN FOR RECORD WITH CAGED SIGHT

Targets with V/R = 0.33 rad/s, 0.66 rad/s and 0.99 rad/s were run against the DFE with a caged sight condition (zero lead angle or zero T_F simulated). Time histories shown in figures 15, 16 and 17 resulted. This aspect of the demonstration was conducted mainly to establish a baseline (minimum tracking) performance for VADS. The degrading effect that a disturbed line of sight system has on tracking accuracy has been documented in numerous studies, with reference 1 and 6 being the latest. The intent was to collect data such that the effect on this particular subject could be quantified. As a bonus, the caged sight condition allowed one to examine the weapon pointing accuracy of a hypothetical gun system with zero time of flight ballistics and a high inertia manual tracking system with approximately 3 to 7 mils of backlash.

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[3] As an option the target can be initially located outside the field of view to simulate a more realistic acquisition process.

The value of such information is the ability to predict increased VADS weapon pointing performance when further reductions in ammunition time of flight are contemplated.

REDUCTION OF TIME HISTORIES

The time histories shown in figures 9 through 17 were reduced every 0.5 seconds. In each case the initial time selected corresponds to a target slant range of approximately 1900 meters.

The raw data taken from these histories extends to a point in time close to target crossover range and is compiled in appendix A. As with any experimental investigation, there is always an uncertainty associated with the data collected. Table 4 lists the various components of uncertainty associated with weapon pointing accuracy and combines it into a root sum square error. Tracking error uncertainty is also shown.

ANALYSIS OF DATA

The data compiled in appendix A was analyzed by using the following formulae to compute various statistical properties.

$$\mu W = \frac{\sum_{i=1}^{N} W_i}{N}, \quad i = 1, 2, 3 \ldots . N \qquad \text{(Mean)}$$

$$\sigma_W{}^2 = \frac{\Sigma W^2{}_i}{N} - \frac{(\Sigma W_i)^2}{N^2}, \quad i = 1, 2, 3 \ldots . N \qquad \text{(Variance)}$$

$$\sigma_W = (\sigma_W)^{1/2} \qquad \text{(Standard Deviation)}$$

$$RMS_W = (\sigma_W{}^2 + \mu_W{}^2)^{1/2} \qquad \text{(Root Mean Square)}$$

The random variables are: W = either WPEE, WPET, TEE, or TET (See list of symbols)

$$Z = (WPEE^2 + WPET^2)^{1/2}$$

$$Y = (TEE^2 + TET^2)^{1/2}$$

$$\text{Radial RMS}_Z = (\sigma_Z^2 + \mu_Z^2)^{1/2}$$ (Radial RMS Weapon Pointing Error)

$$\text{Radial RMS}_Y = (\sigma_Y^2 + \mu_Y^2)^{1/2}$$ (Radial RMS Tracking Error)

Results of these computations appear in table 5 where radial RMS weapon pointing and tracking errors are summarized for M246, hollow and zero T_F ammunition as a function of V/R ratio. This data was employed to compute a percent reduction in radial RMS weapon pointing error when hollow ballistics were utilized in lieu of M246. The independent variable selected was V/R ratio and a plot is shown in figure 18. Percent improvement is given by

$$\frac{\text{M246 Radial RMS WPE - Hollow Radial RMS WPE}}{\text{M246 Radial RMS WPE}} \times 100.$$

The curve shown was extrapolated backwards to give an indication of performance between hover and a V/R approaching 0.3 rad/s. A further reduction of data resulted in table 6, which lists the radial RMS weapon pointing error averaged over the three V/R ratios employed. The reader should focus attention on the grand averages associated with weapon pointing and tracking. In essence standard Vulcan appears as a 24.0 mil system and Vulcan with hollow ballistics an 18.0 mil system for a net improvement of 27 percent. Tracking accuracy is hardly impacted (4 percent). When the weapon pointing error data shown is plotted as a function of each round's inverse muzzle velocity figure 19 results. VADS accuracy payoffs resulting from further reduction in time of flight (increased muzzle velocity) can be inferred from this curve.

In closing, appendices B and C present information for modifying the elliptical 18 mil x 8 mil muzzle clamp, the "ready to fire light" and the Acquisition Time Delay (ATD) circuitry for hollow ammunition (see reference 6).

RECOMMENDATIONS

1. Investigate a target with a V/R = 0.1 rad/s, and a helicopter "pop up" and hover maneuver.

2. Conduct acquisition simulations by placing the target outside the field of view. Measure effect on system reaction time.

3. Conduct at least five replications per V/R ratio per gunner.

4. Mechanize data reduction using new statistical software package and magnetic tape on mainframe computer.

5. Utilize M246 and hollow round lethalities in an investigation to determine VADS effectiveness in terms of P_K. Consider cost effectiveness.

6. Utilize at least two gunners instead ot one.

7. Determine the ballistics of the actual hollow round in flight for Eg = 30°.

8. Determine the impact of hollow round ballistics on ATD and ready to fire light circuitry.

9. Design an optimal muzzle clamp for the hollow round. Base dimensions on ammunition dispersion and weapon pointing error.

10. Investigate VADS accuracy against accelerating targets with M246 and hollow round ballistics.

11. Conduct firing tests against live targets after accomplishing 7 through 10 above.

12. Conduct similar assessments as those described above using PATEC round ballistics.

13. Utilize the DFE to measure the accuracy of a PIVADS type configuration (reference 7) with M246 hollow and PATEC round ballistics.

14. Perform a closed loop tracking experiment with the DFE (reference 8). This mode of operation will eliminate the gunner's variability from the experiment, and thus allow quantitative comparisons of individual test results to be made for the three targets and two ammunitions. Basically, the closed loop performance is achieved by observing reticle position and comparing it with target position which is stored in the DFE computer. Commands which attempt to null the difference between these two signals are supplied to the turret

servos in place of the normal hand grip signals produced by the gunner. Primitive loop closure attempts have been successful in the past and have shown tracking behavior similar to gunners. Figure 20 shows this preliminary result.

CONCLUSIONS

1. Overall gains in gun system accuracy look promising with hollow round ballistics employed in the VADS fire control computer (sight current generator).

2. A grand average weapon pointing accuracy improvement of 28.06 percent in train and 11.06 percent in elevation was observed when hollow round ballistics were employed in the VADS fire control computer.

3. Since lead angles to be developed are smaller when hollow ammunition is employed, the length of time ATD should be shortened.

4. The elliptical 18 mil x 8 mil muzzle clamp should be modified for hollow ballistics since these dimensions were probably determined from M246 firing data.

5. Since the effective range of hollow ballistics is greater than that of the M246, the ready to fire light should come on earlier.

6. Overall system reaction time should be reduced if circuits associated with conclusions 3 and 5 are mechanized.

7. Further reductions in time of flight will increase weapon pointing accuracy.

8. Since tracking accuracy was essentially equivalent for all the data analyzed, its sensitivity to ballistics appears negligible. This conclusion contradicts a similar one found in reference 1.

9. Examination of tracking error records and statistics indicates that the same number of burst can be fired from VADS when either hollow or M246 ballistics are employed against the same target geometry. This conclusion contradicts a similar one found in reference 1.

10. The probability of hit along course will be greater with hollow ballistics than M246 ballistics when employed in the Vulcan fire control computer.

REFERENCES

1. Meridith and Fournfelker, "An Investigation of Modification to the Vulcan Air Defense Systems' Sight Current Generator", TR 245, AMSAA, Aberdeen Proving Ground, Maryland, February 1979.

2. Chestnut and Mayer, Servomechanisms and Regulating System Design, John Wiley and Sons, Inc., Publisher, 1955.

3. D. B. Ellis, "VADS SCG Modification", Technical Report 79APB501, General Electric Co., Burlington, VT, January 1978.

4. FC Board, Ft. Bliss, TX, Ballistic Data for the 20mm Tubular Projectile Comparison of Data from Midi and Hawk, Report 78-AB-30, 8 May 1979.

5. "Preliminary Operation and Maintenance Instructions for VADS Dynamic Field Evaluator", ACS 10158-1 Vol. 1, General Electric Co., Binghamton, NY 19 March 1973. Revised 10 April 1973.

6. Vulcan Air Defense System (VADS) Improvement Project, Fleet Systems Dept., John Hopkins University, Applied Physics Laboratory, FS-76-070, Final Report Summary, April 1976.

7. Executive Summary for the Preliminary Design Study of a Digitally Stabilized and Controlled Brassboard Director Type Fire Control System for the Product Improved Vulcan (VADS), Robert S. Segal, Frankford Arsenal Report Number FA-TR-76048, August 1976.

8. The Feasibility of Utilizing the Dynamic Field Evaluator (DFE) as a Vulcan System Acceptance Tester (VSAT), Pg. 30, R. Border & R. Segal, Rock Island Arsenal Report Number R-TR-75-002, January 1975.

9. Goode and Machol, Systems Engineering, McGraw Hill, Inc., 1957, pp 150-152.

Table 1. Tubular (hollow) round ballistics.

T_F (Sec)	Ground Range (Meters)	Altitude (Meters)	Velocity (m/sec)	Slant Range (Meters)
0.000	0.000	0.000	1280.160	0.000
0.100	108.233	62.440	1219.595	124.953
0.200	211.414	121.869	1162.567	244.025
0.300	309.860	178.476	1109.379	357.585
0.400	403.899	232.452	1059.865	466.013
0.500	493.834	283.976	1013.757	569.662
0.600	579.953	333.218	970.957	668.865
0.700	662.538	380.343	931.303	763.948
0.800	741.845	425.501	894.488	855.211
0.900	818.108	468.830	860.242	942.922
1.000	891.538	510.452	828.349	1027.327
1.100	962.335	550.486	798.723	1108.658
1.200	1030.685	589.039	771.152	1187.131
1.300	1096.757	626.211	745.429	1262.940
1.400	1160.703	662.090	721.376	1336.261
1.500	1222.659	696.756	698.830	1407.254
1.600	1282.750	730.281	677.657	1476.061
1.700	1341.087	762.732	657.706	1542.814
1.800	1397.770	794.165	638.822	1607.625
1.900	1451.981	824.104	599.224	1669.506
2.000	1502.747	852.099	561.524	1727.519
2.100	1550.397	878.254	526.027	1781.870
2.200	1595.078	902.685	492.958	1832.789
2.300	1637.088	925.532	463.176	1880.559
2.400	1676.562	946.958	436.512	1925.511
2.500	1713.904	967.104	412.526	1967.932
2.600	1749.278	986.094	390.854	2008.073
2.700	1782.874	1004.033	371.188	2046.148
2.800	1814.853	1021.013	353.275	2082.345
2.900	1845.360	1037.114	336.898	2116.828
3.000	1874.528	1052.414	322.230	2149.751
3.100	1903.535			

Reference 3 was modified for the tubular round.

Projectile weight	=	58.688 grams (0.131 lbs)
Projectile reference area	=	3.142 cm^2 (3.382E-3 $ft.^2$)
Launch velocity	=	1280.16 m/s (4200 ft/s)
Launch angle	=	30°
Integration time	=	0.01 seconds
Temperature	=	15°C (59°F), sea level standard conditions
Barometric pressure	=	760mm mercury, sea level standard conditions

Table 2. M246 round ballistics.

Time of Flight (sec)	Range (Meters)
0.1	100
0.21	200
0.33	300
0.45	400
0.59	500
0.73	600
0.89	700
1.06	800
1.25	900
1.45	1000
1.68	1100
1.93	1200
2.2	1300
2.5	1400
2.82	1500
3.15	1600
3.49	1700
3.86	1800
4.23/4.63	1900/2000

Gun elevation = 0^{o}
Sea level standard conditions

Table 3. Flight path and mount conditions.

V/R (rad/s)	Time to crossover (seconds)	V (m/s)	R (meters)	X (meters)	H (meters)	Ø (radians)	Ego (mils)	Eto (mils)
0.33	28.0	77.0	233.3	2169.0	180.0	3.0335	83.4	84.3
0.66	26.3	155.0	234.8	4090.0	180.0	3.0848	44.8	44.8
0.99	17.6	232.0	234.3	4090.0	180.0	3.0848	44.8	44.8

Pitch of mount = -0.67 mils
Roll of mount = -11.17 mils

Table 4. Component error sources for VADS-DFE.

Target Center Uncertainty (millirads)	Radar Target Simulator (millirads)	Mount Attitude Measurement (millirads)	Gun Elevation Position Measurement (millirads)	Sight Attachment Gyros (millirads)	Display (millirads)	Computer (Nova 1200) Data Processing (millirads)	Strip Chart Recorder (millirads)	Reading Strip Chart Paper (millirads)	polynomial Fit Error (millirads)
.5/axis	.22	.10	.02	.46	1.36	.55[a]	1.33	.66	Included under data processing.

RSS = $(.5^2 + .22^2 + .10^2 + .02^2 + .46^2 + 1.36^2 + .55^2 + 1.33^2 + .66^2)^{1/2}$

RSS = 2.21 millirads (uncertainty in measuring VADS WPE when M246 ballistics are utilized)[b]

a. This value is less than .55 millirads for Hollow Ballistics since it was computed using an M246 fit error of 3.64 msec. RMS. The time of flight fit error for Hollow Ballistics is .383 msec. RMS.

b. The uncertainty in measuring VADS tracking error is .89 millirads for either ammunition.

Table 5. Radial RMS weapon pointing and tracking error summary.

	M246		Tubular		Zero T_F[a]	
V/R (rad/s)	Radial RMS weapon pointing error (millirads)	Radial RMS tracking error (millirads)	Radial RMS weapon pointing error (millirads)	Radial RMS tracking error (millirads)	Radial RMS weapon pointing error (millirads)	Radial RMS tracking error (millirads)
0.33	13.82	3.39	9.15	3.78	3.57	3.57
0.66	39.77	10.42	25.80	9.35	11.03	11.03
0.99	18.90	4.94	17.81	4.89	4.63	4.63

[a] Sight caged.

Table 6. Radial RMS weapon pointing and tracking error averaged over V/R = 0.33, 0.66, 0.99 rad/s.

	M246 Round	Hollow Round	Percent Improvement[a]	Zero T_F[b]
Average RMS WPE	21.13	15.20	28.06	5.27
Average RMS WPEE	8.41	7.48	11.06	3.56
Average RMS WPE	24.16	17.59	27.19	6.41
Average RMS TE	6.25	6.01	3.84	6.41

[a]Percent improvement = $\frac{\text{M246 - Hollow}}{\text{M246}}$ X 100

[b]Sight caged

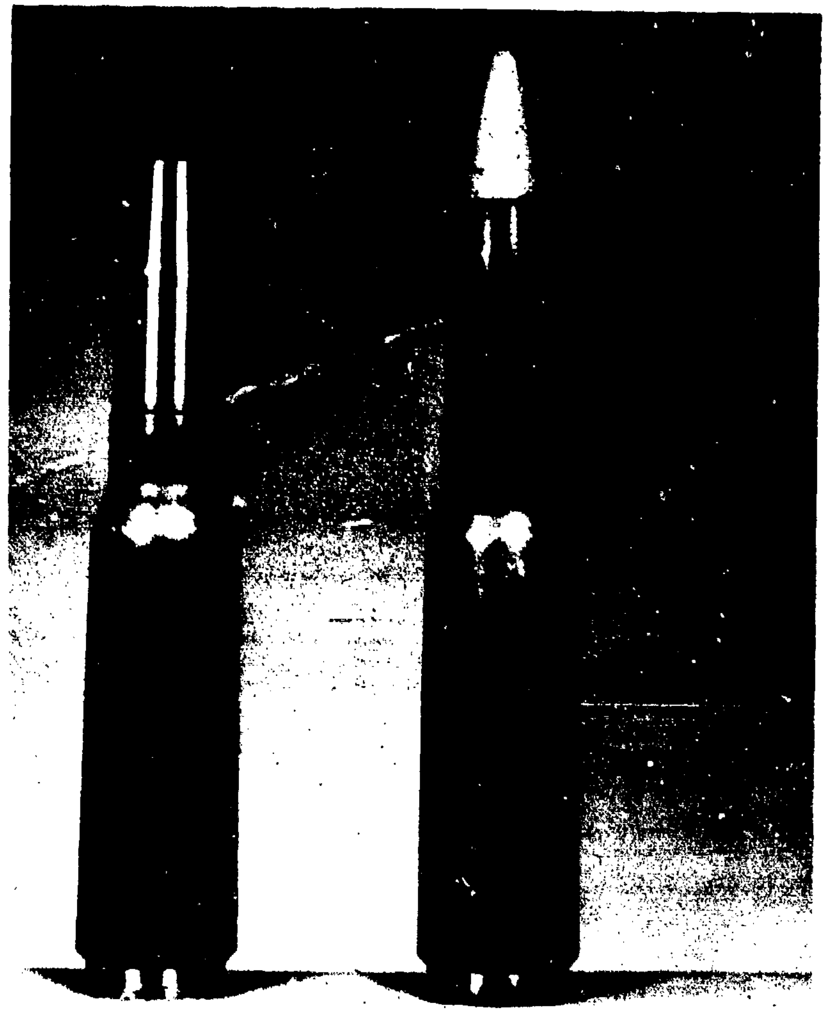

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Figure 1. Tubular and M246 rounds.

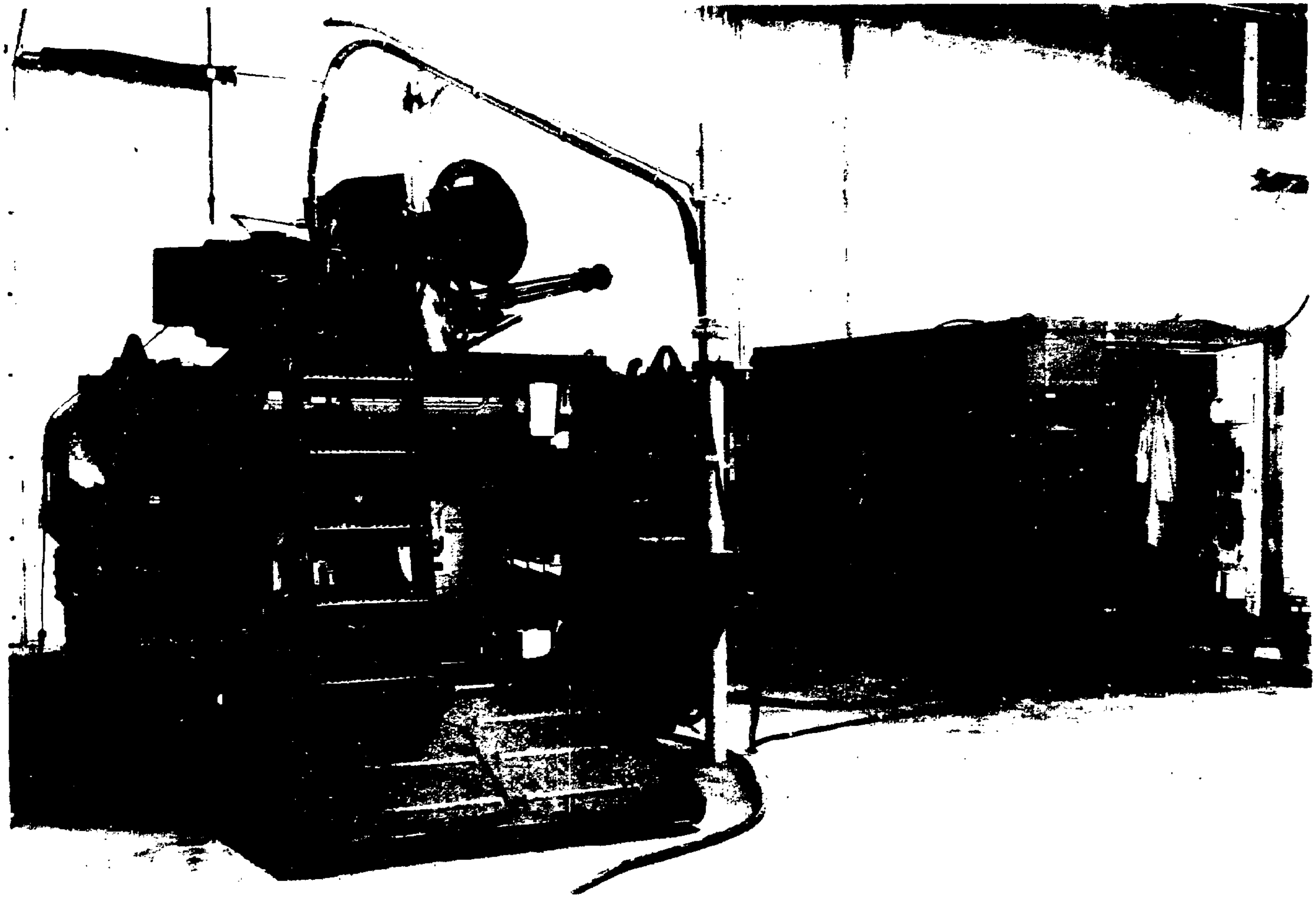


Figure 2. DFE and VADS test station.

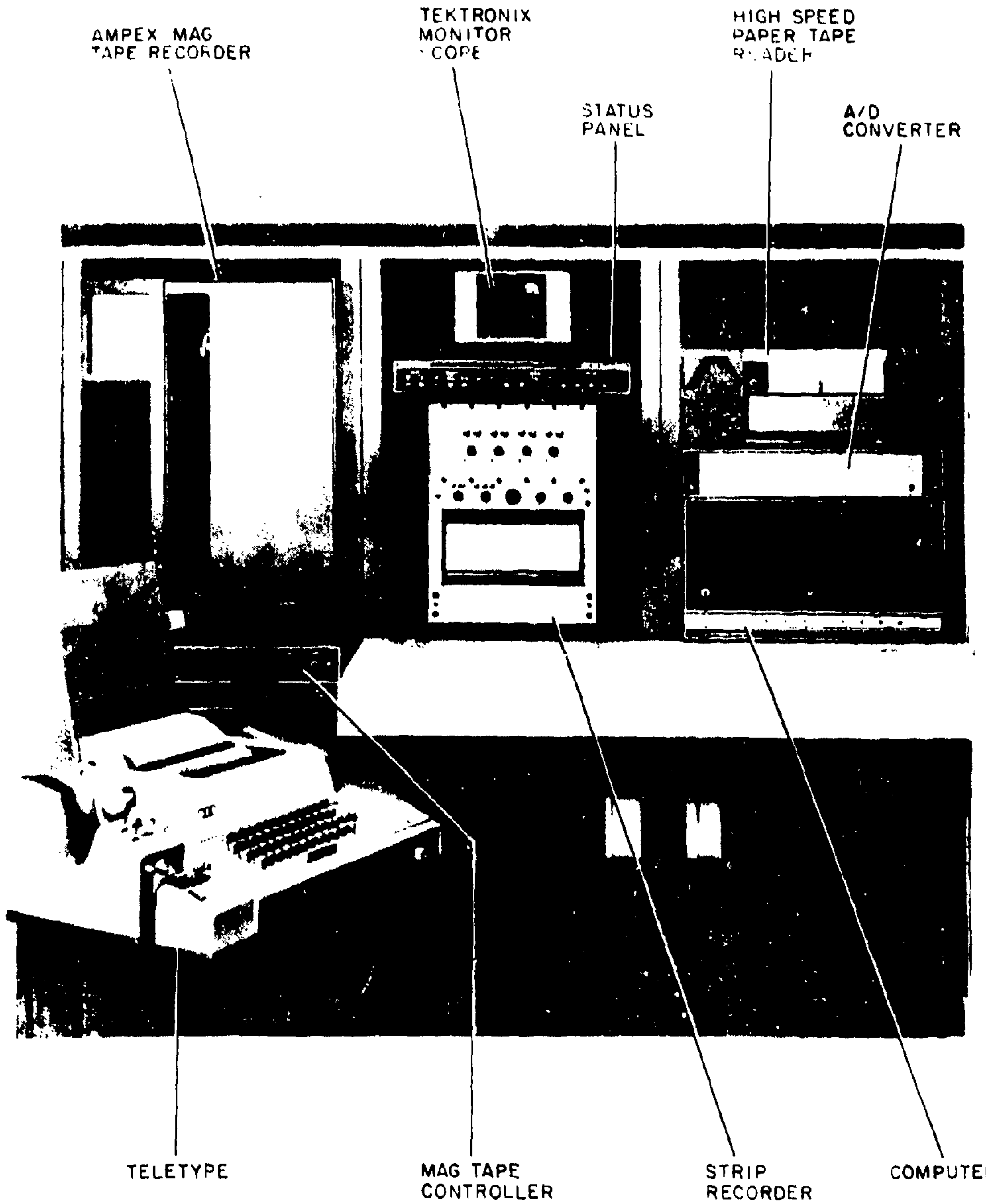


Figure 3. Console.

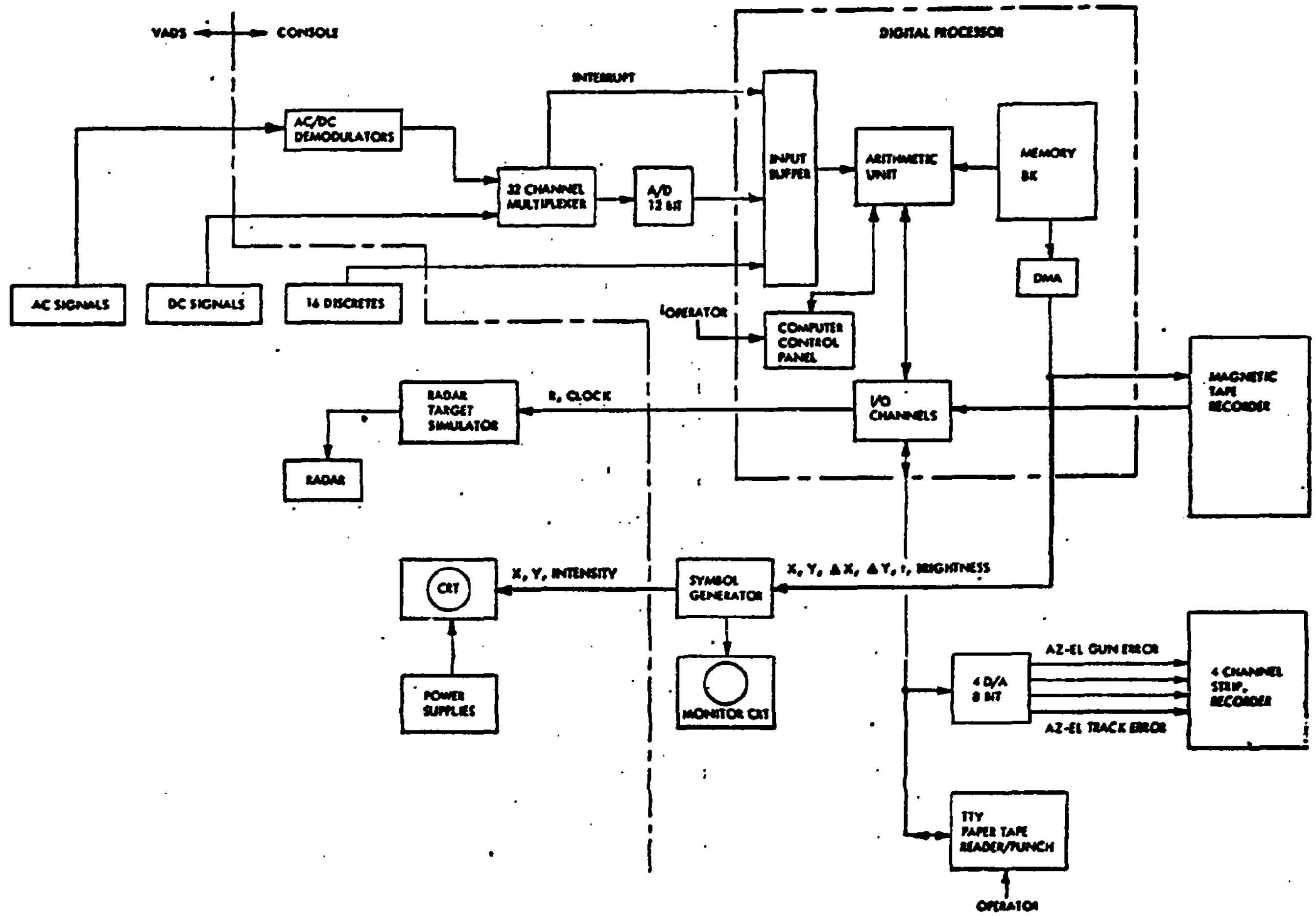


Figure 4. Dynamic field evaluator (DFE) block diagram.

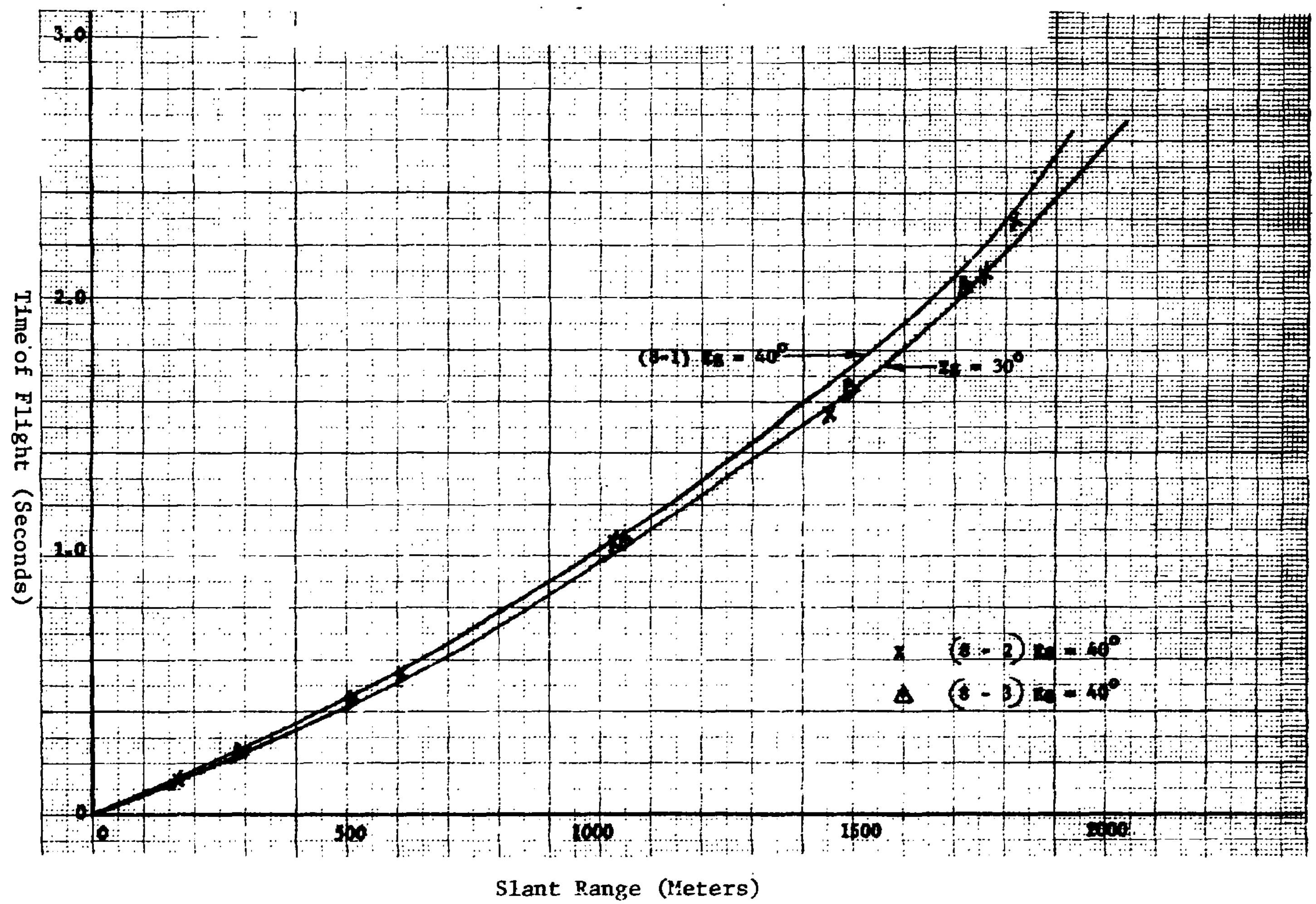


Figure 5. Comparison of validated ($Eg = 40^{o}$) ballistics with non-validated theoretical ($Eg = 30^{o}$) ballistics.

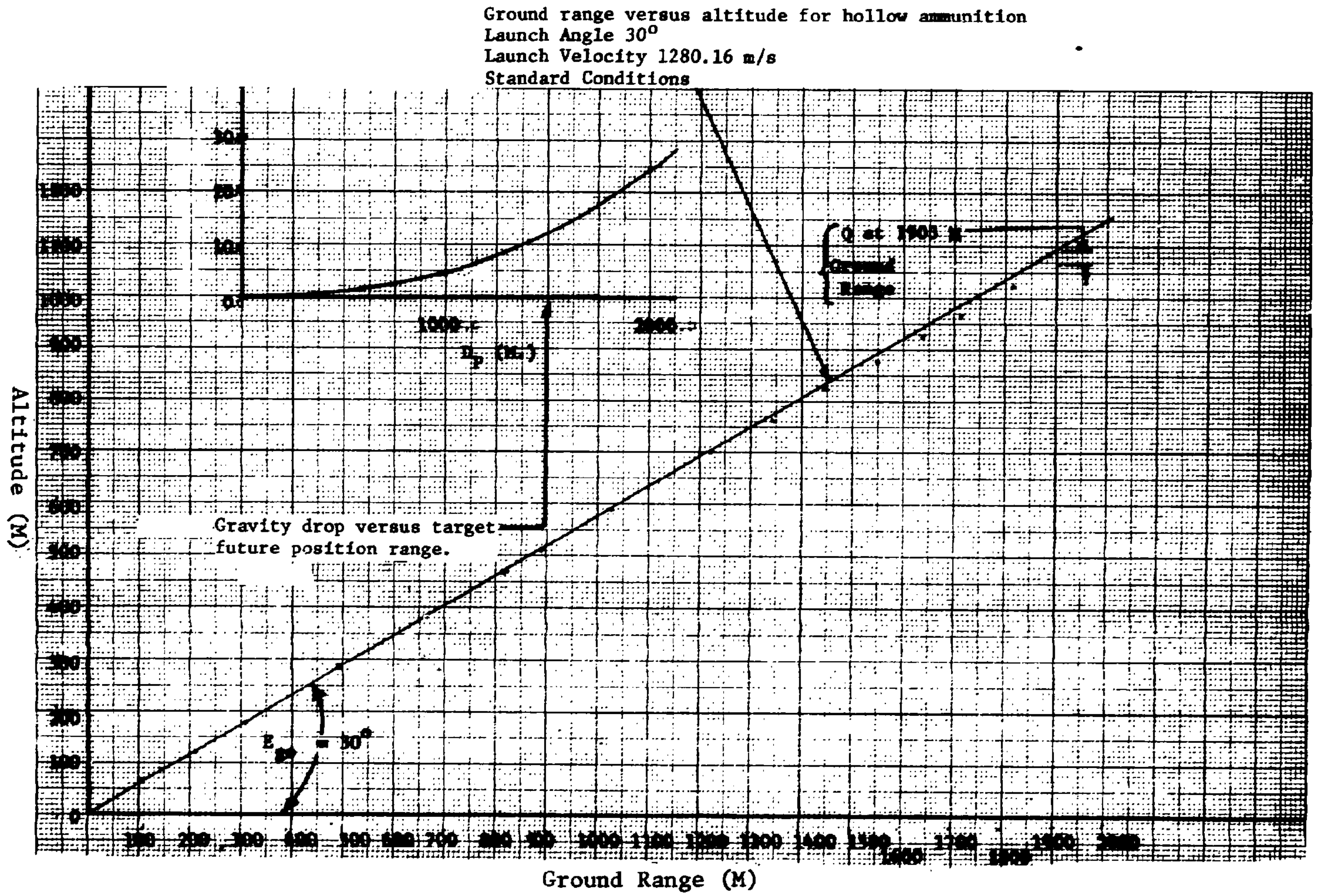


Figure 6. Ground range versus altitude, and gravity drop versus target future position range.

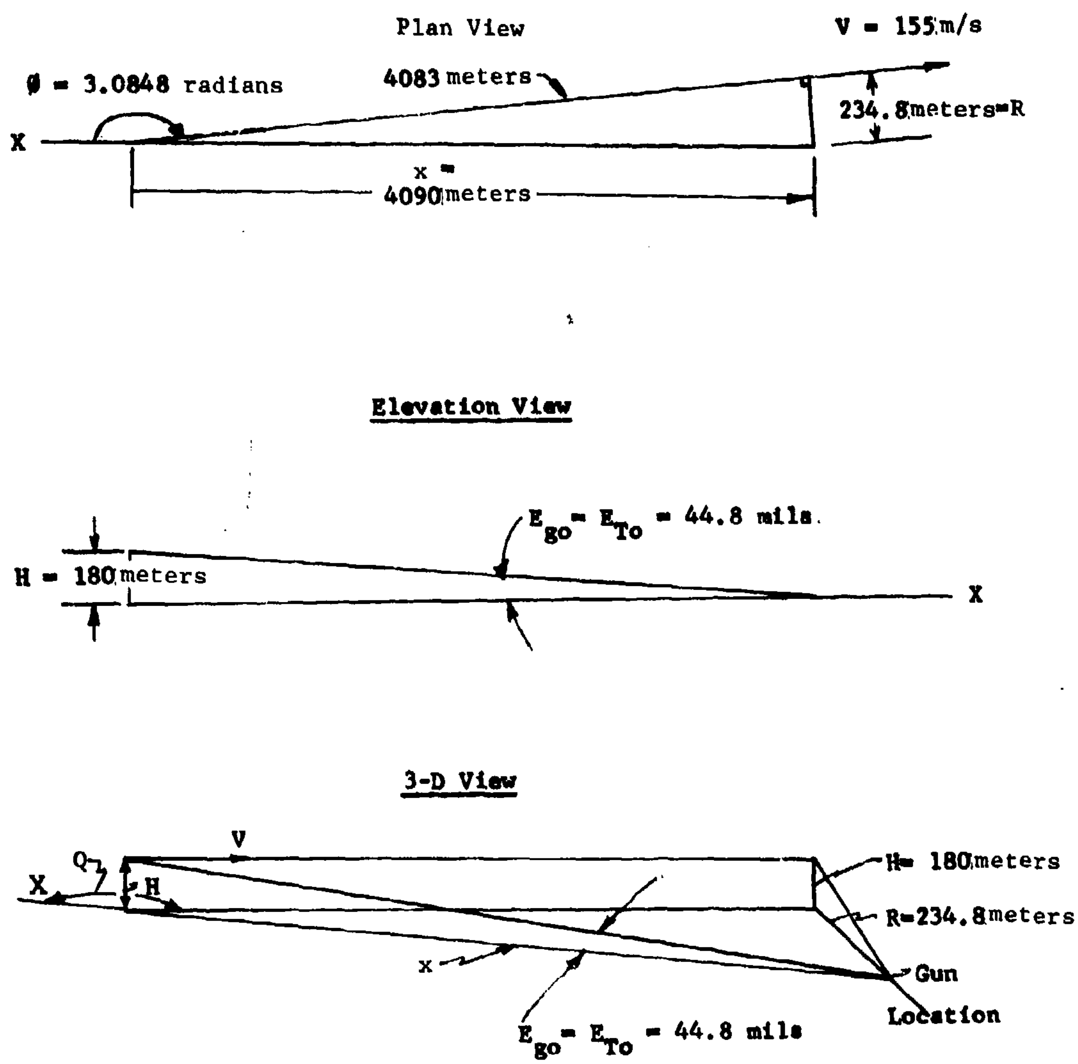


Figure 7. Flight path geometry (V/R = 0.66 rad/s).

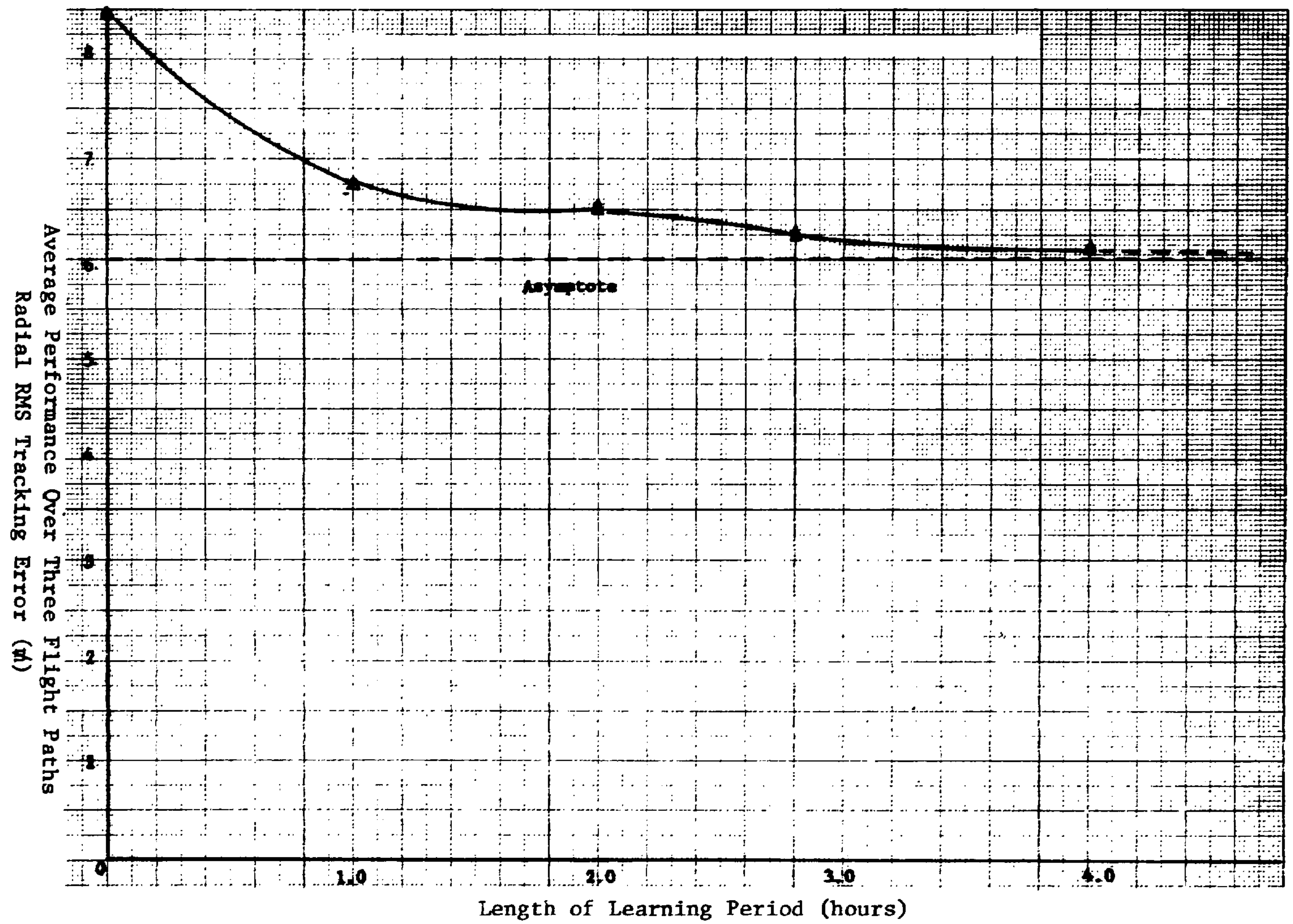


Figure 8. Learning performance as a function of time.

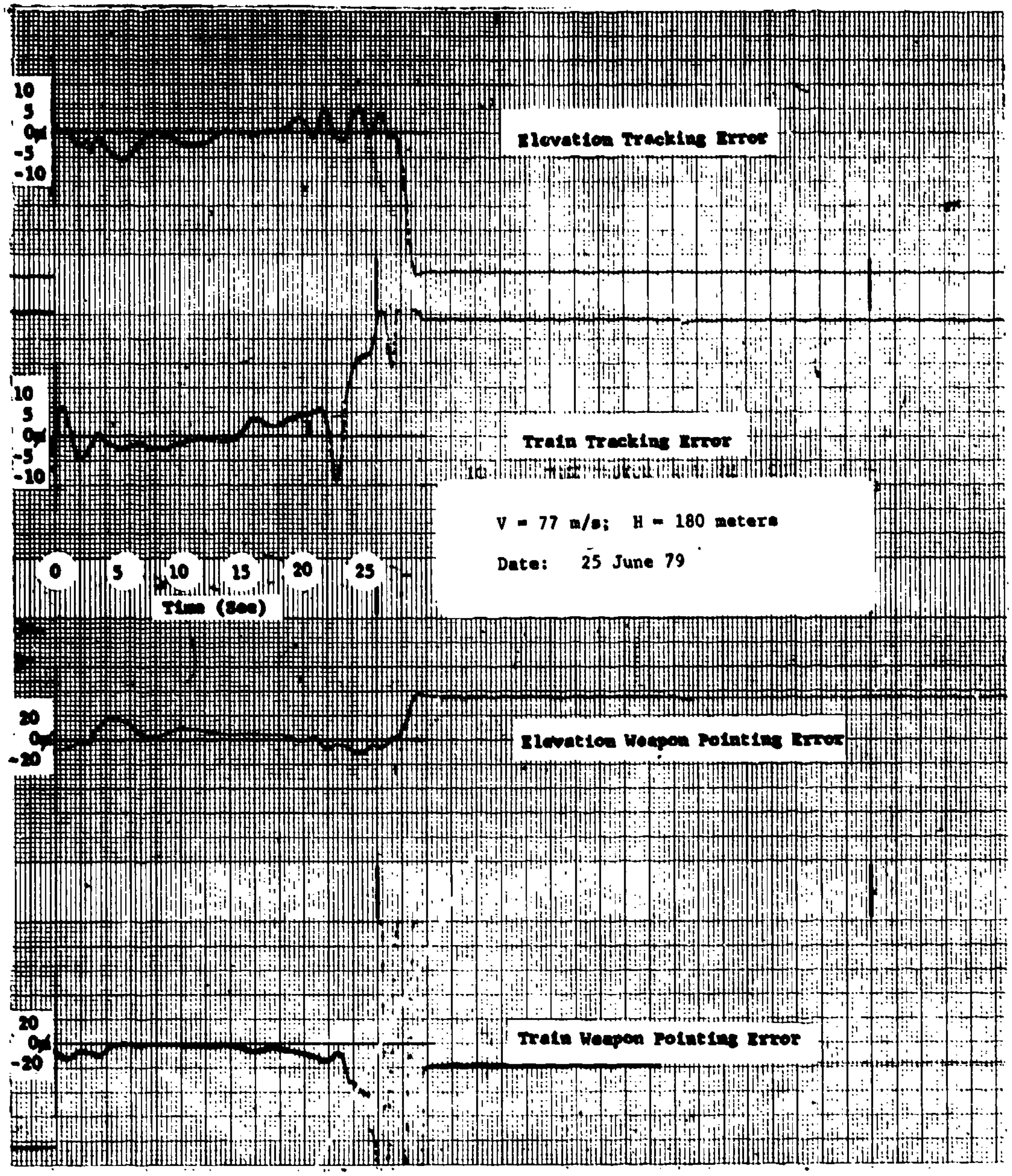


Figure 9. Hollow round time histories with sight uncaged (V/R = 0.33 rad/s).

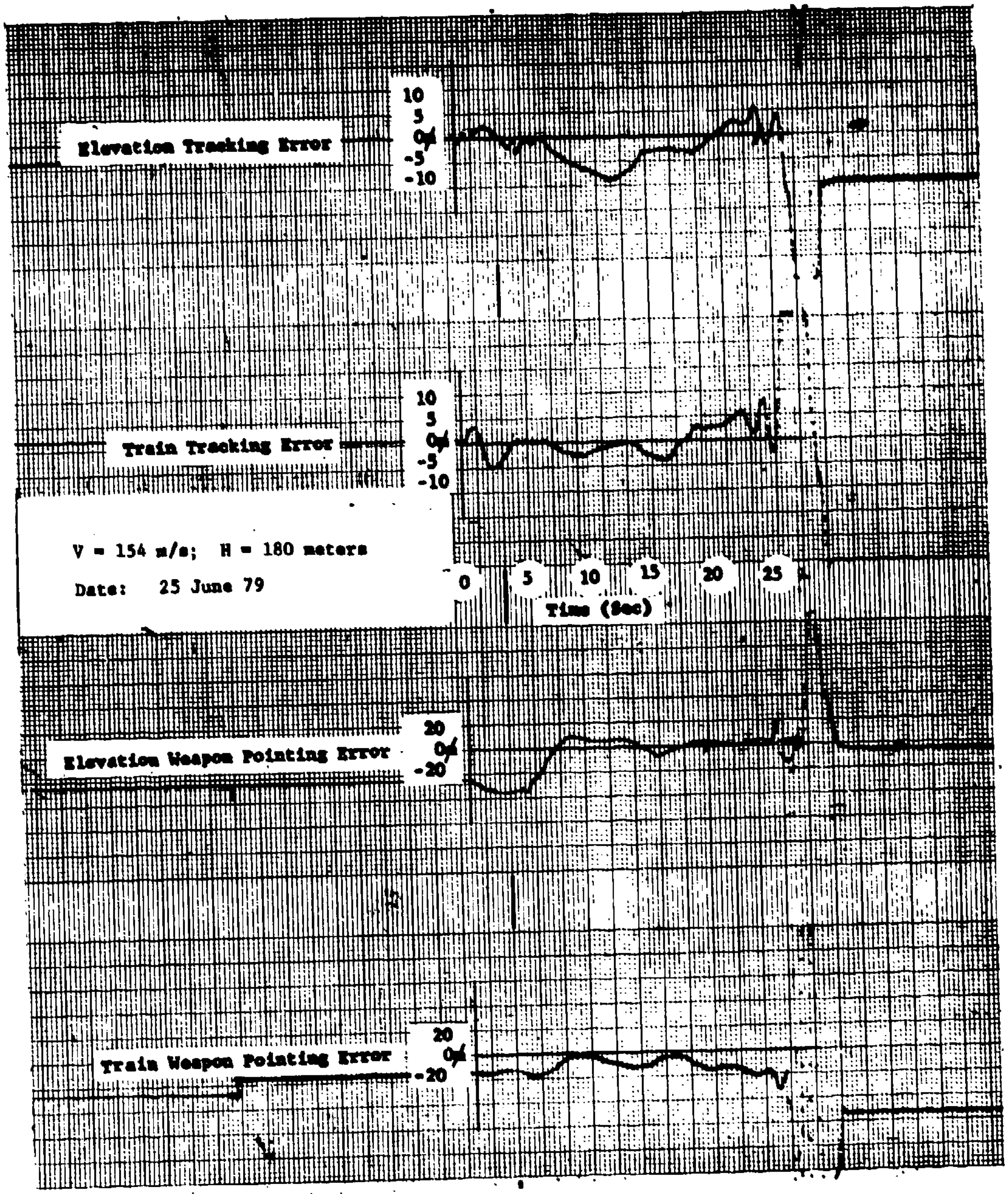


Figure 10. Hollow round time histories with sight uncaged (V/R = 0.66 rad/s).

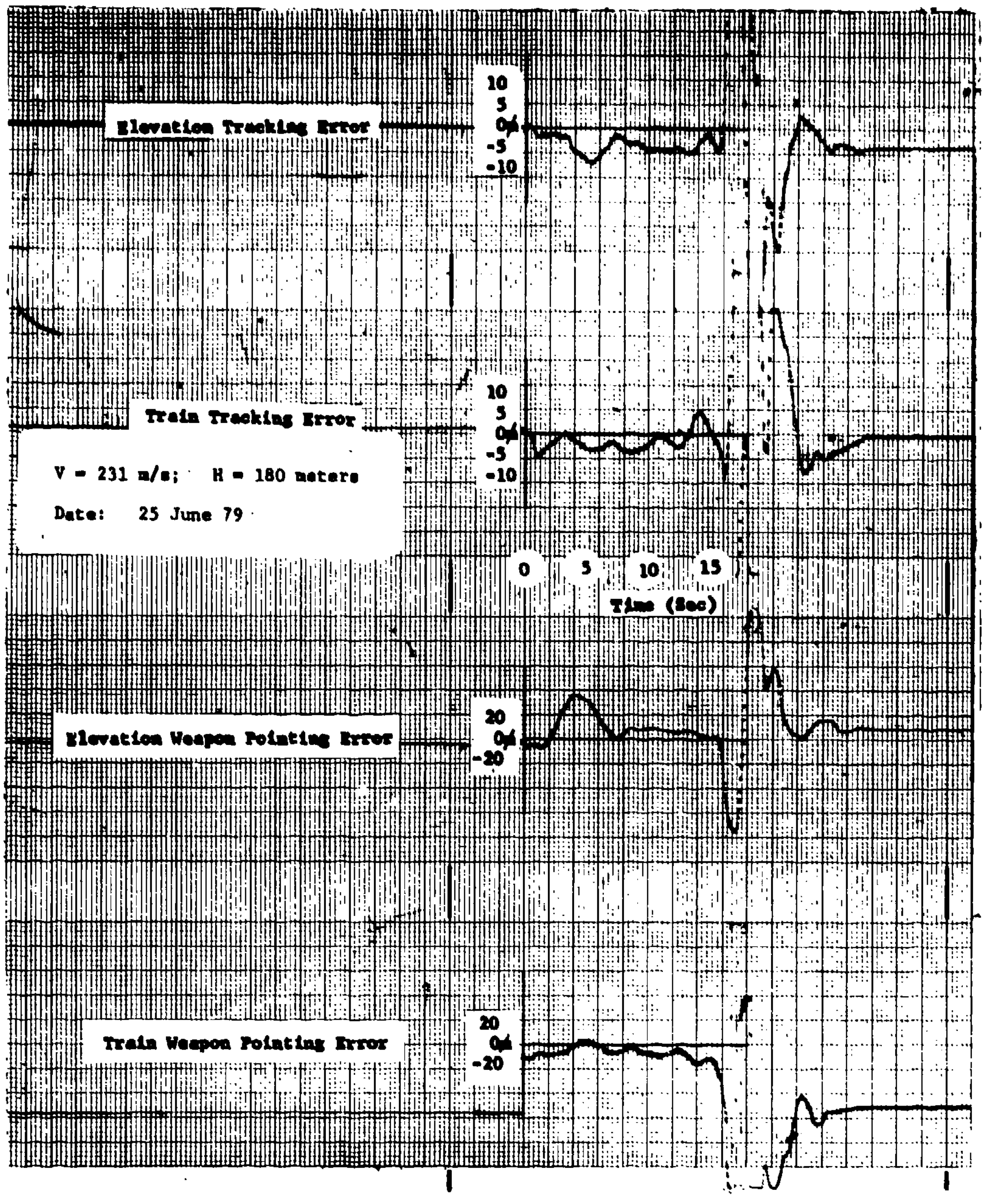


Figure 11. Hollow round time histories with sight uncaged (V/R = 0.99 rad/s).

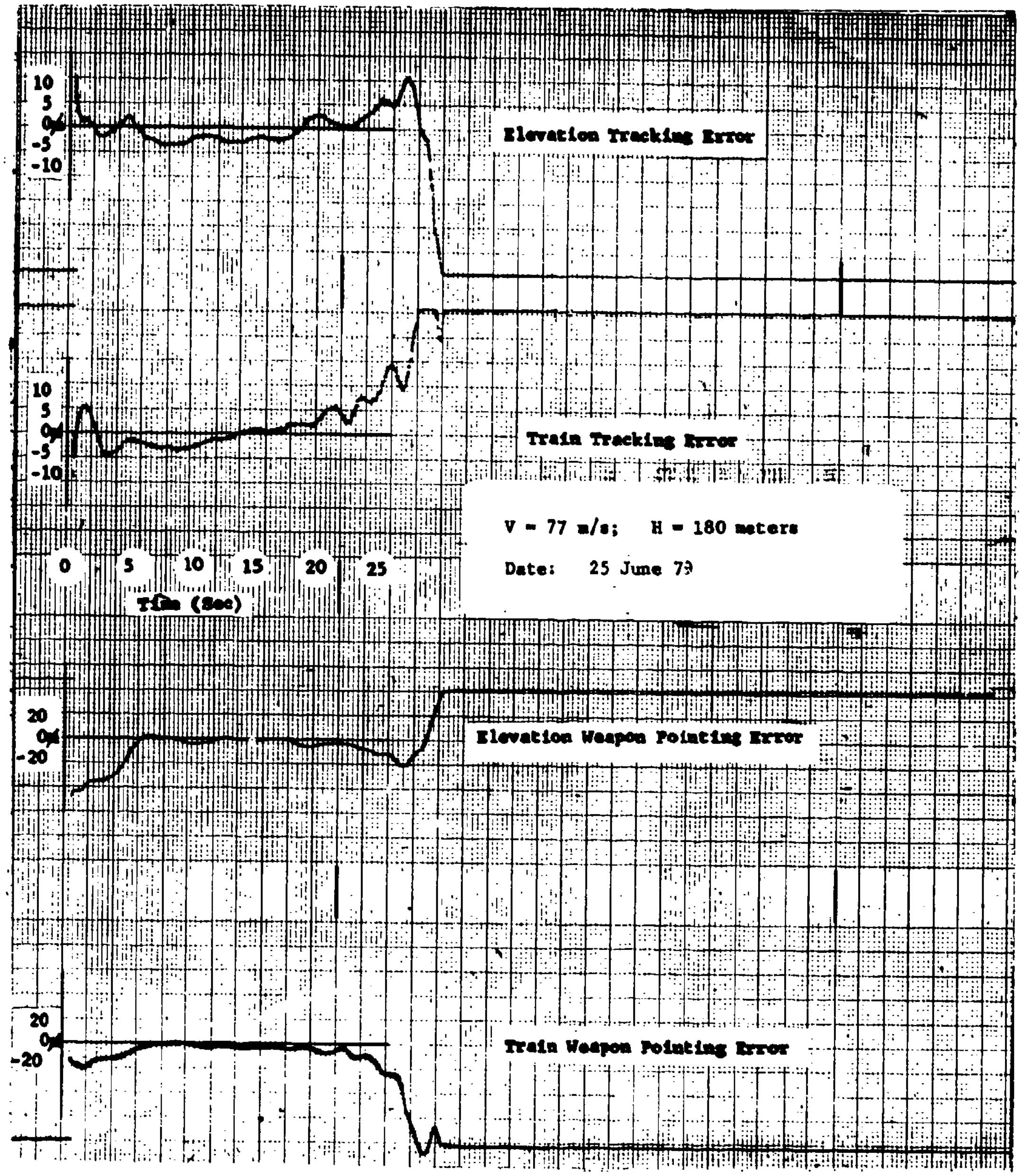


Figure 12. M246 time histories with sight uncaged (V/R = 0.33 rad/s).

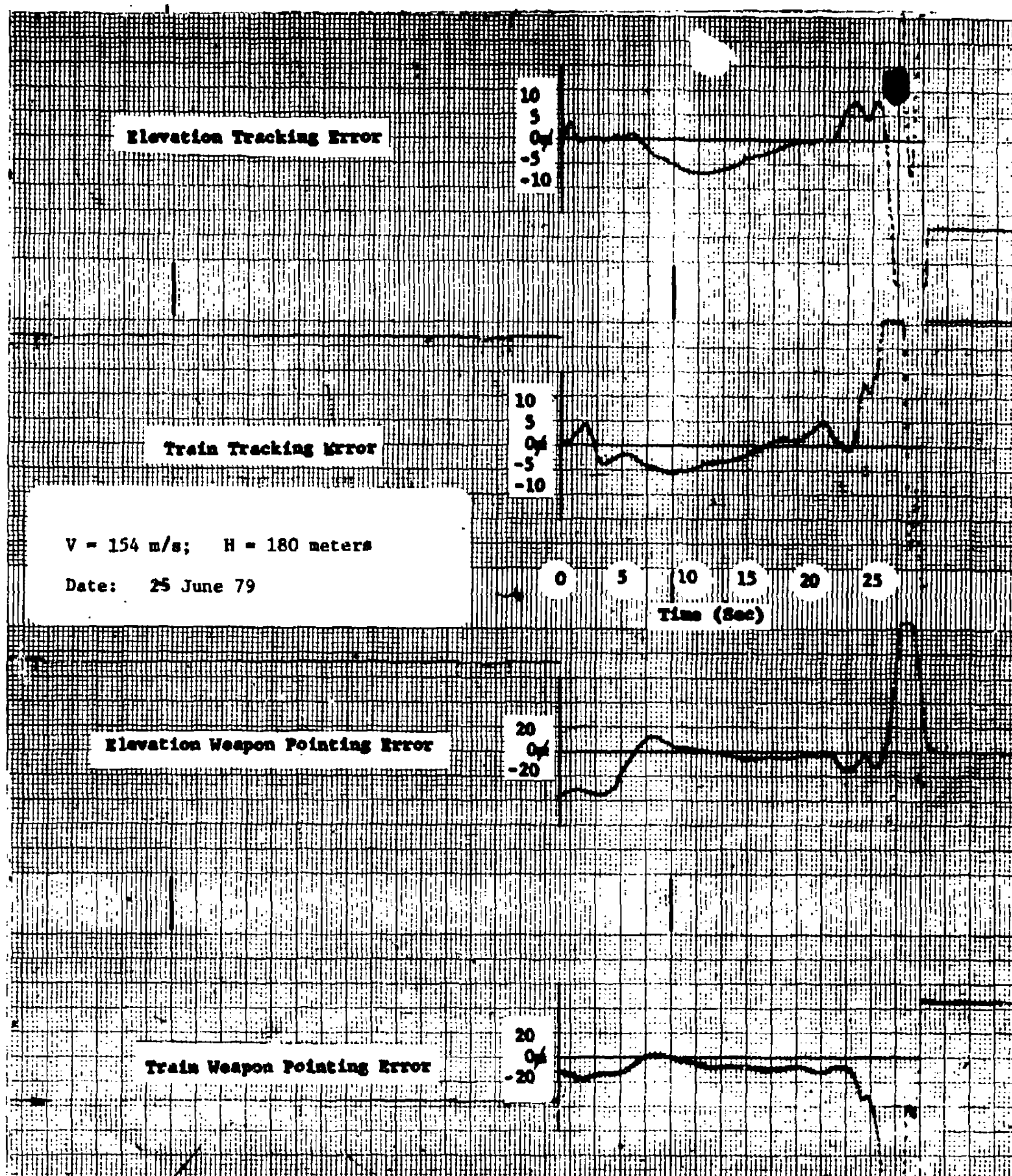


Figure 13. M246 time histories with sight uncaged (V/R = 0.66 rad/s).

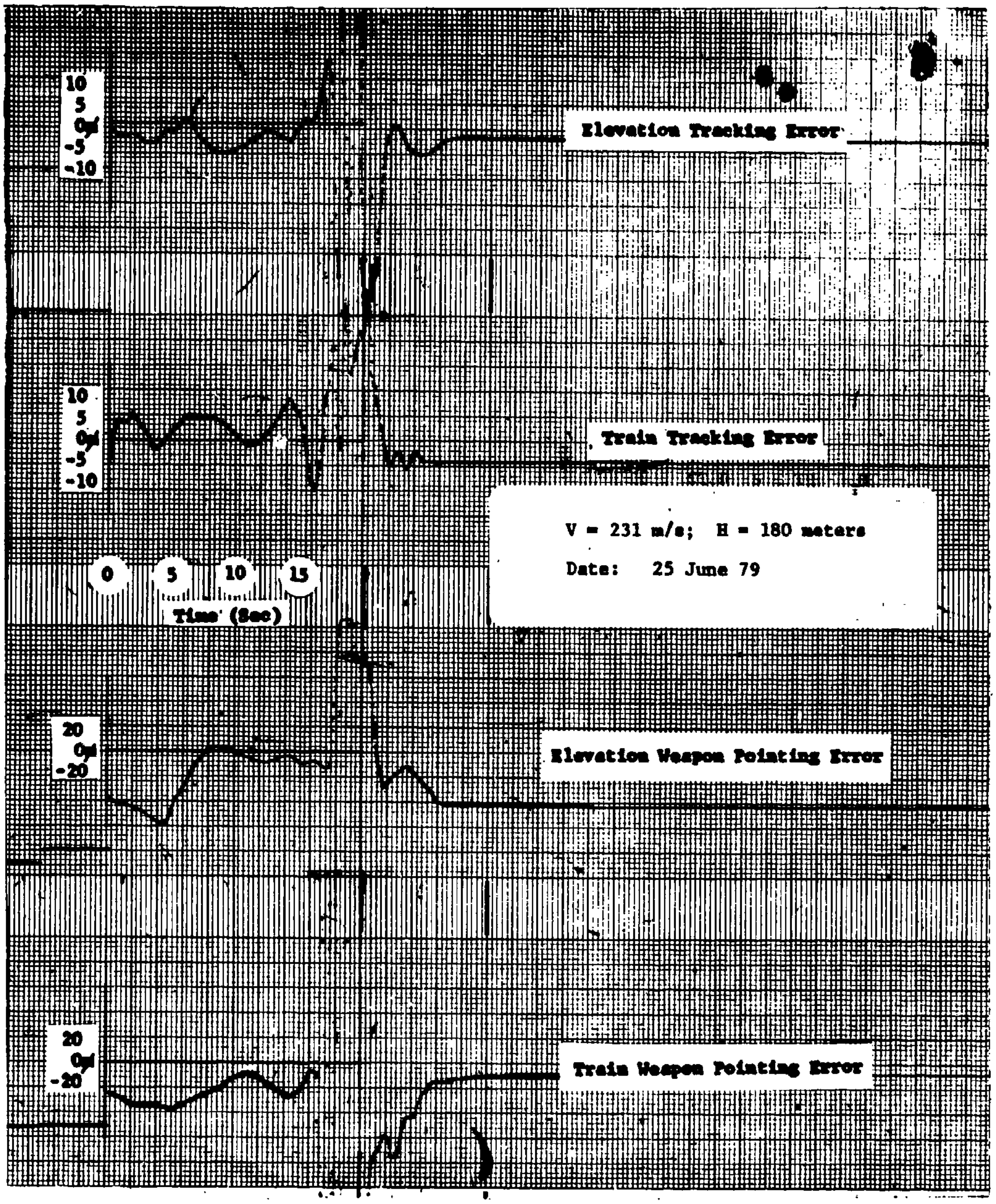


Figure 14. M246 time histories with sight uncaged (V/R = 0.99 rad/s).

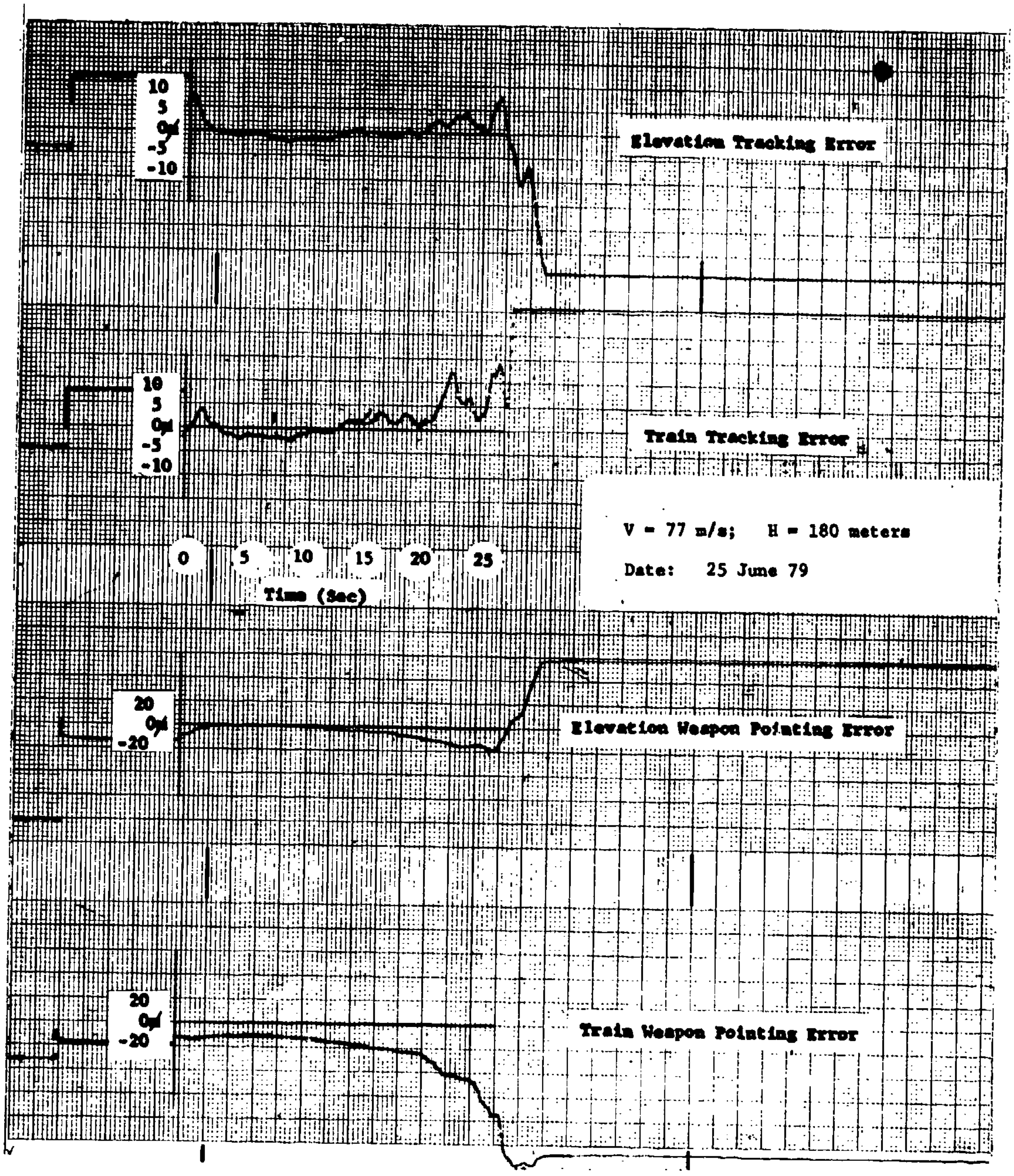


Figure 15. Time histories with sight caged (V/R = 0.33 rad/s), assuming a zero time-of-flight projectile.

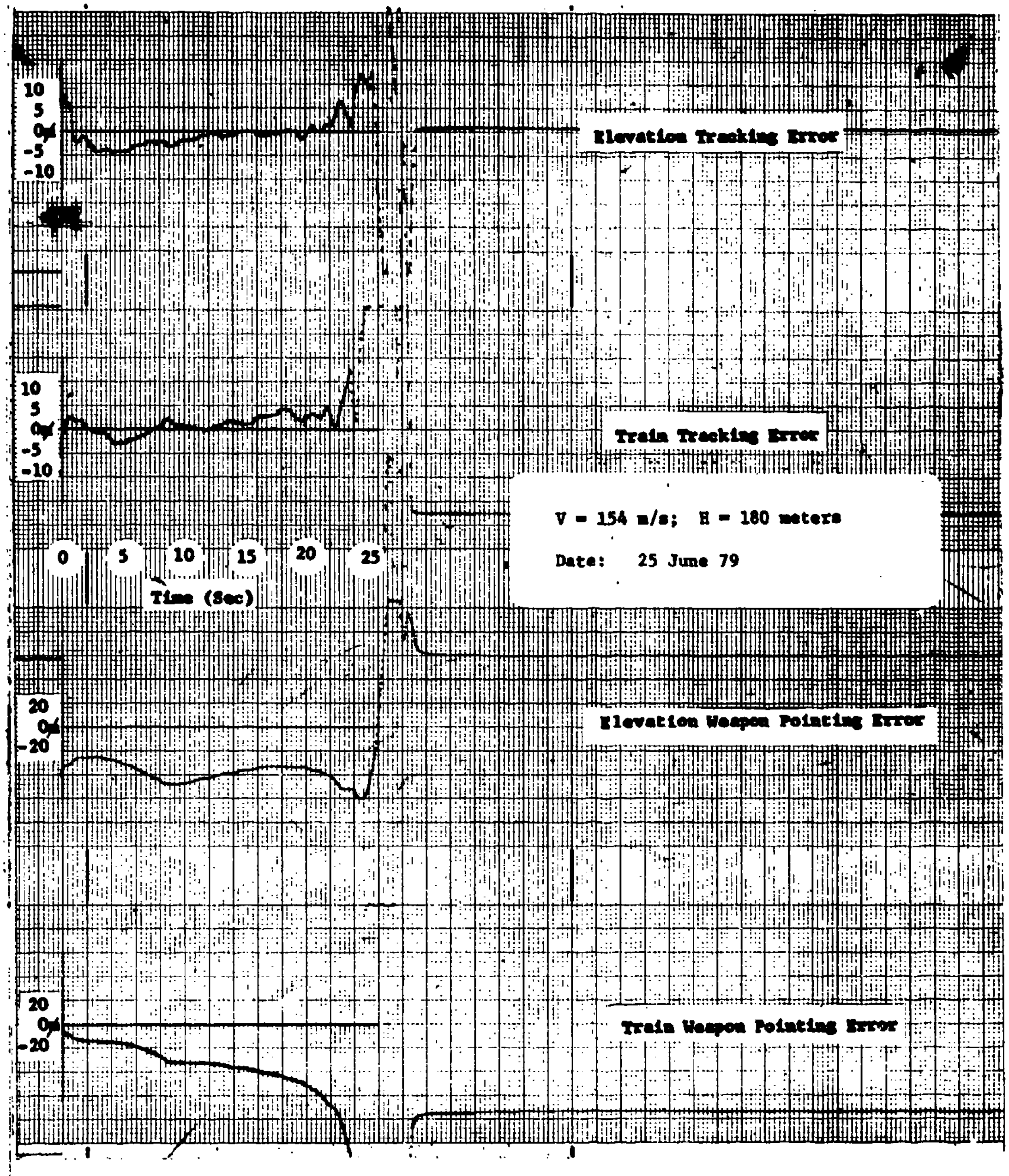


Figure 16. Time histories with sight caged (V/R = 0.66 rad/s), assuming a zero time-of-flight projectile.

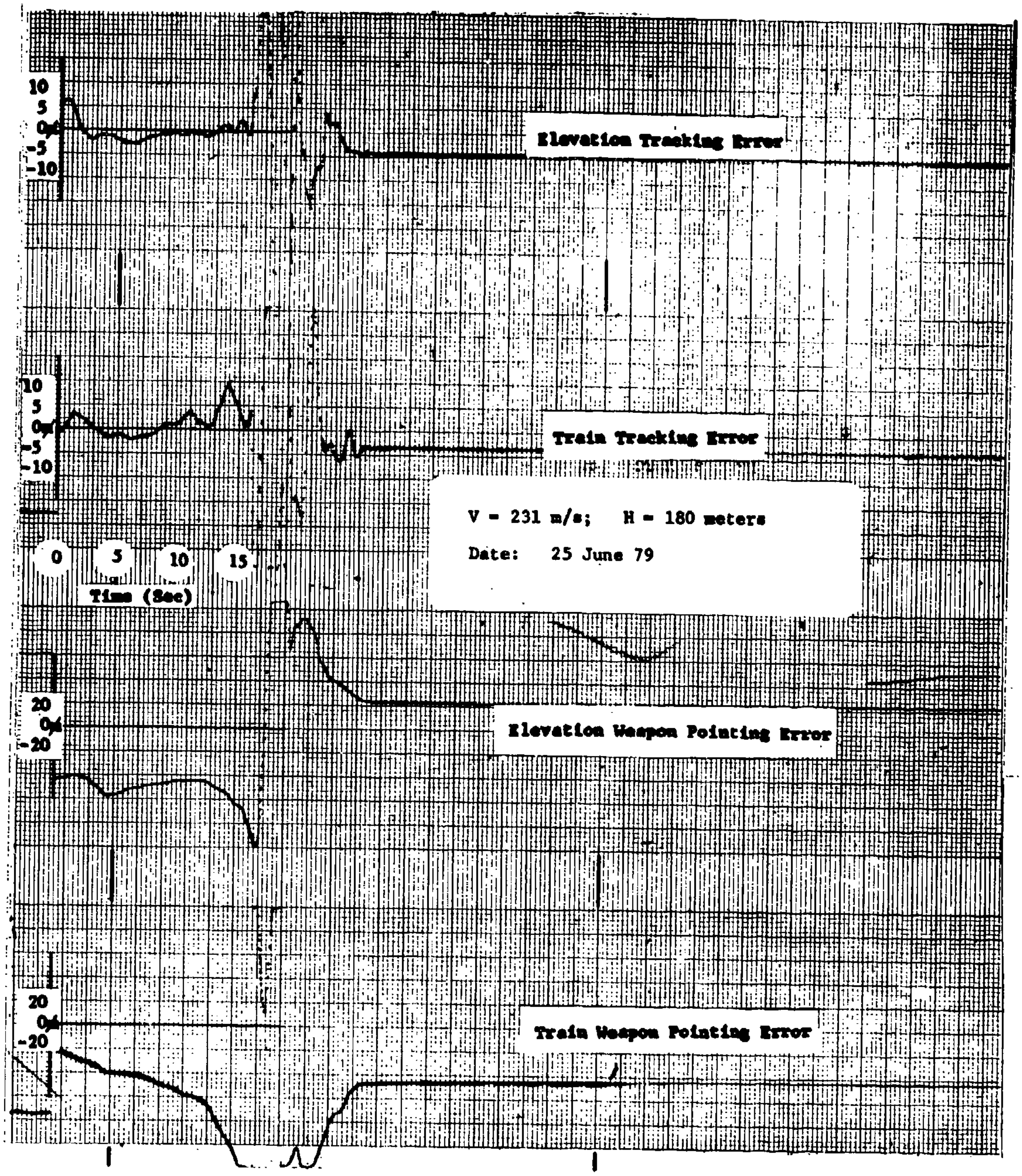


Figure 17. Time histories with sight caged (V/R = 0.99 rad/s), assuming a zero time-of-flight projectile.

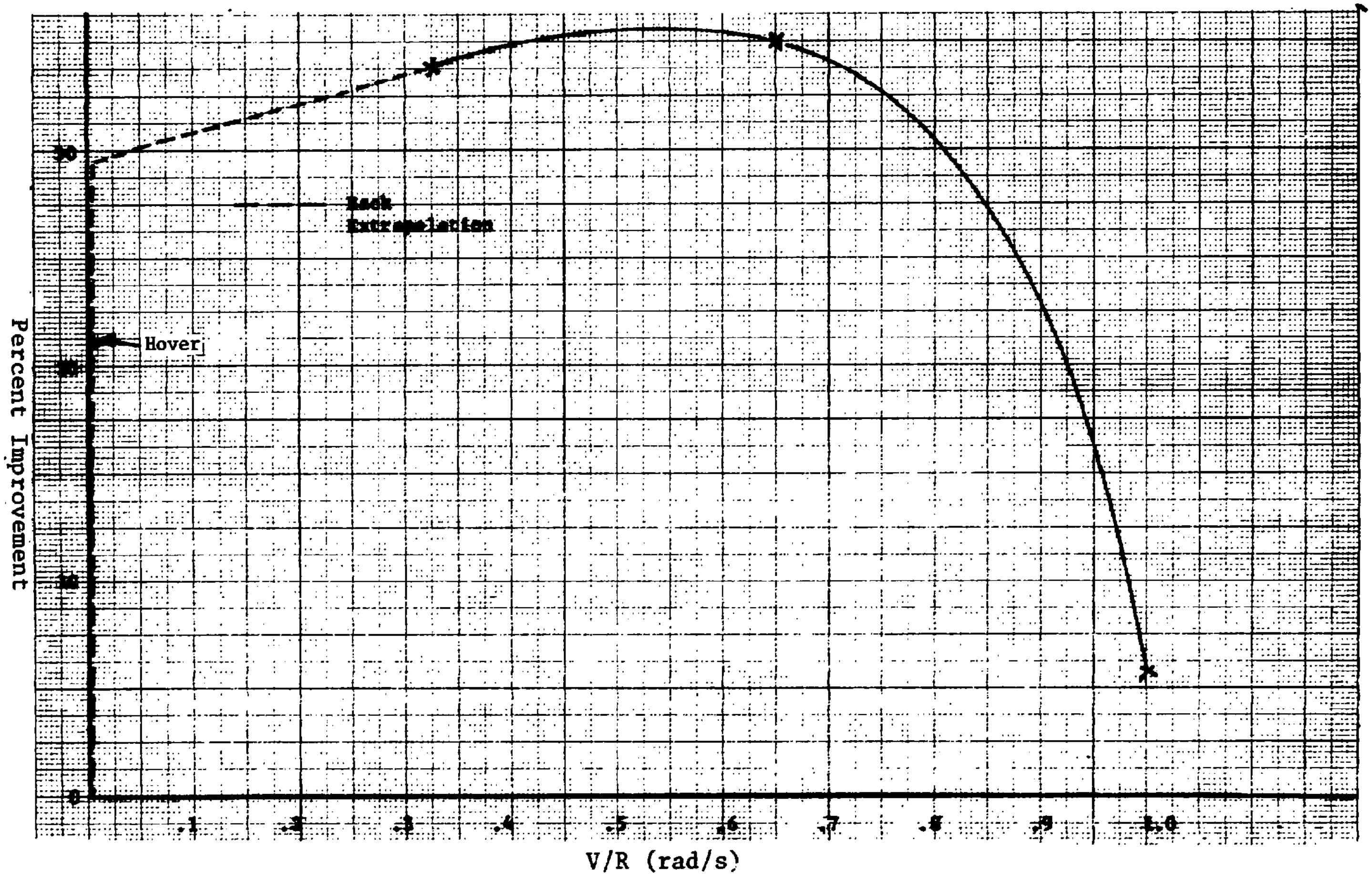


Figure 18. Percent reduction in radial weapon pointing error when hollow round ballisticc are utilized in lieu of M246 ballistics.

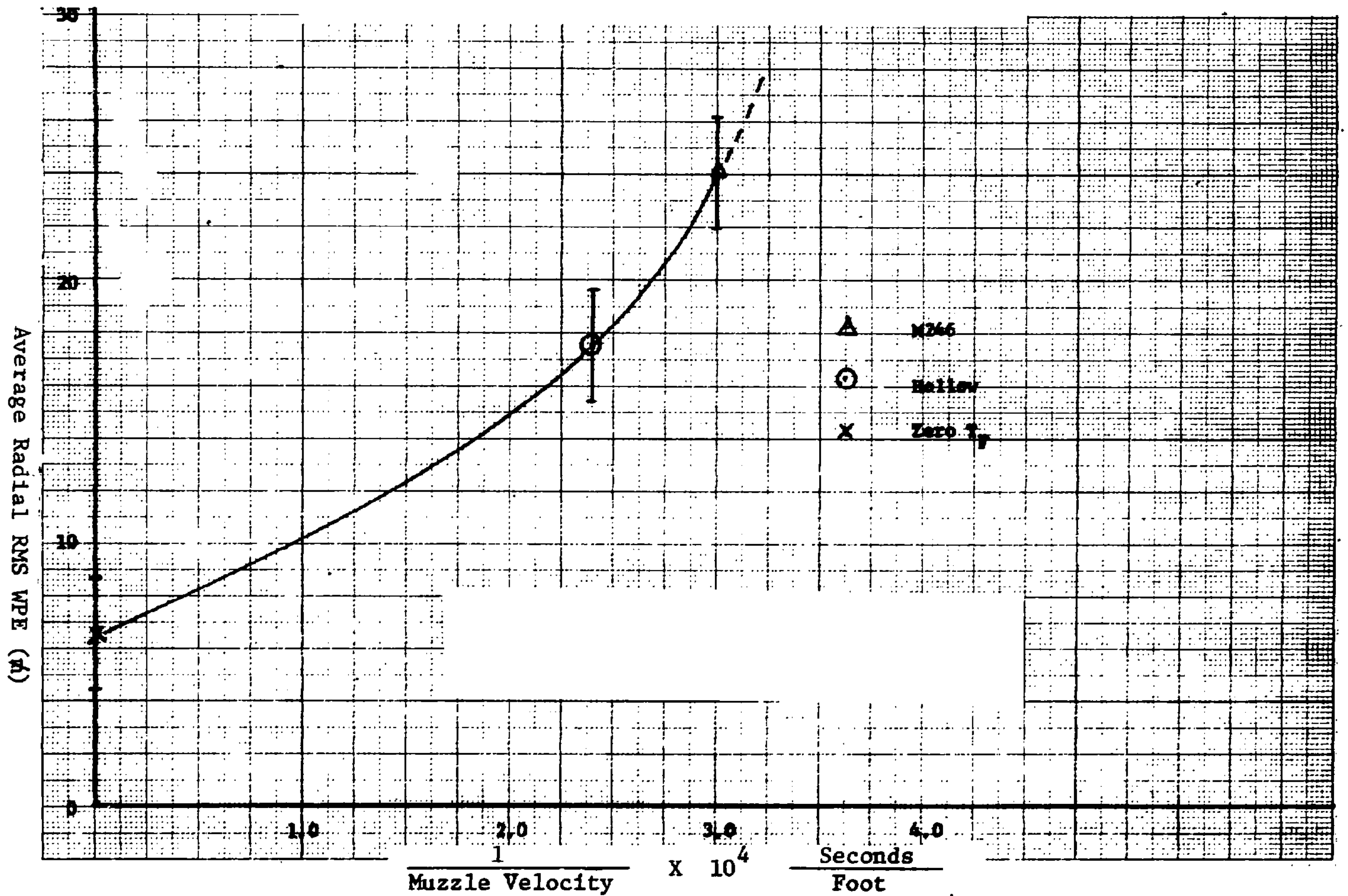
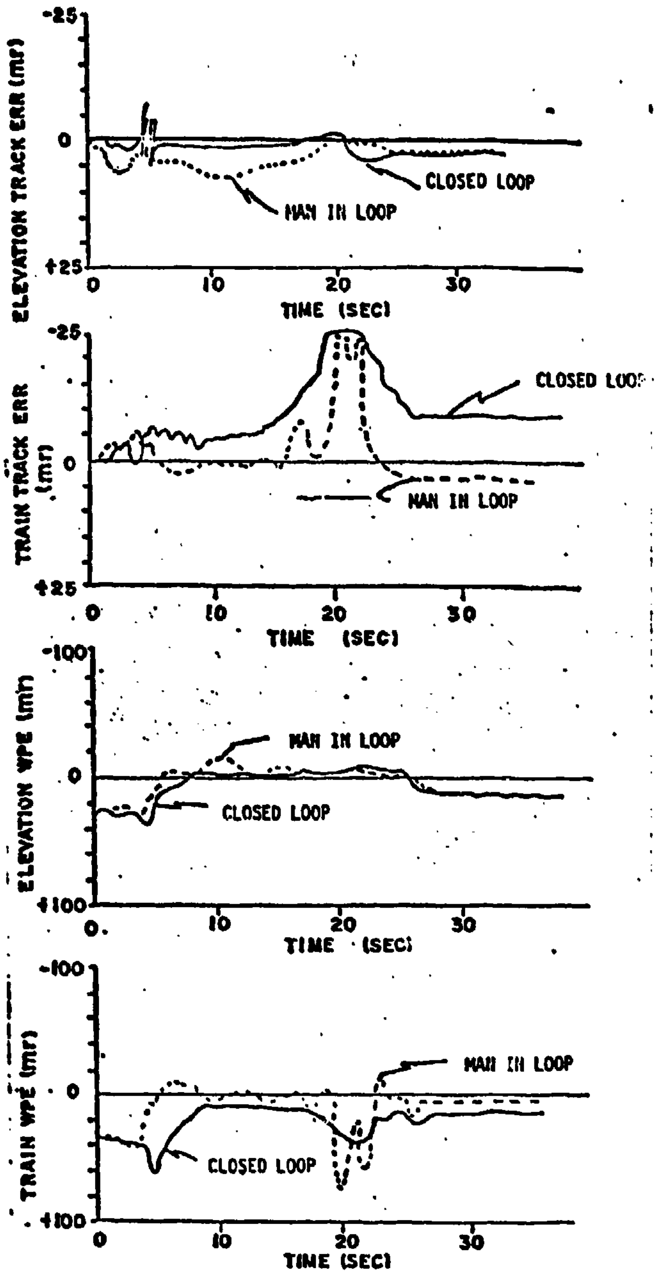


Figure 19. Radial RMS weapon pointing error averaged over V/R = 0.33, 0.66, 0.99 rad/s versus inverse muzzle velocity.



COURSE PARAMETERS

VELOCITY 350 KTS.
ALTITUDE 350 MET.
GROUND CROSSING
RANGE 850 MET.
TIME TO CROSSOVER
22.7 SEC.

CONDITIONS ON
FIELD VADS

OPEN LOOP GAIN
UNKNOWN
ATD OPERATING
ZERO TRACKING
ERROR @ t = 0
NON-ZERO WEAPON
POINTING ERROR
@ t = 0
COURSE PARAMETERS
ABOVE

CONDITIONS ON
CLOSED LOOP
DFE/VADS

OPEN LOOP GAIN
APPROX. 3 ATD
OPERATING
ZERO TRACKING
ERROR AT t = 0
NON-ZERO WEAPON
POINTING ERROR
@ t = 0
COURSE PARAMETERS
ABOVE

Figure 20. Closed loop testing.

APPENDIX A

RAW DATA FOR WEAPON POINTING AND TRACKING ERROR

VERSUS TIME AND V/R

Appendix A.

V/R = .33 M246 Round

Time (sec)	WPEE (%)	WPET (%)
2.5	-37	-16
3	-36	-14
3.5	-34	-13
4	-30	-12
4.5	-36	-11
5	-30	-11
5.5	-16	- 8
6	- 2	- 6
6.5	2	- 4
7	2	- 2
7.5	2	- 2
8	0	- 1
8.5	0	- 1
9	- 1	- 1
9.5	- 3	- 1
10	- 4	- 1
10.5	- 4	- 2
11	- 3	- 2
11.5	- 3	- 3
12	- 2	- 3
12.5	- 1	- 3
13	0	- 2
13.5	0	- 3
14	- 1	- 4
14.5	- 1	- 4
15	- 1	- 5
15.5	- 1	- 4
16	- 1	- 3
16.5	- 1	- 3
17	- 1	- 2
17.5	- 1	- 3
18	0	- 4
18.5	- 3	- 3
19	- 5	- 3
19.5	- 6	- 3
20	- 6	- 5
20.5	- 5	- 7
21	- 4	- 8
21.5	- 4	- 8
22	- 3	- 7
22.5	- 3	- 7
23	- 5	- 7

V/R = .33 Hollow Round

Time (sec)	WPEE (%)	WPET (%)
2.5	- 4	- 6
3	4	- 8
3.5	10	- 7
4	16	- 4
4.5	18	0
5	17	0
5.5	16	0
6	12	0
6.5	8	0
7	5	0
7.5	2	0
8	2	0
8.5	4	0
9	6	0
9.5	8	0
10	9	0
10.5	9	0
11	8	0
11.5	8	0
12	7	0
12.5	6	0
13	5	0
13.5	4	0
14	4	0
14.5	4	- 2
15	4	- 4
15.5	4	- 5
16	4	- 7
16.5	4	- 6
17	4	- 4
17.5	4	- 4
18	4	- 4
18.5	4	- 4
19	2	- 6
19.5	0	- 7
20	0	- 8
20.5	1	- 9
21	2	-11
21.5	- 3	-12
22	- 6	-16
22.5	- 4	- 8
23	- 4	- 8

Appendix A. (Continued)

V/R = .66 M246 Round

Time (sec)	WPEE (m)	WPET (m)
13.58	- 4	- 8
14.0	- 4	- 8
14.5	- 5	- 8
15.0	- 6	- 8
15.5	- 6	- 8
16.0	- 5	- 8
16.5	- 4	- 8
17.0	- 4	- 8
17.5	- 4	- 8
18.0	- 4	- 8
18.5	- 5	- 8
19.0	- 4	- 8
19.5	- 4	- 9
20.0	- 4	- 10
20.5	- 4	- 11
21.0	- 4	- 12
21.5	- 4	- 11
22.0	- 4	- 8
22.5	-10	- 8
23.0	-12	- 8
23.5	-12	- 13
24.0	-10	- 26
24.5	- 4	- 32
25.0	-10	- 38
25.5	- 8	- 76
26.0	0	-120
26.34	16	-128

V/R = .66 Hollow Round

Time (sec)	WPEE (m)	WPET (m)
13.58	0	-12
14.0	- 2	-10
14.5	- 5	- 6
15.0	- 8	- 4
15.5	- 5	- 4
16.0	- 4	- 4
16.5	- 2	- 5
17.0	0	- 9
17.5	1	-12
18.0	4	-14
18.5	4	-15
19.0	4	-16
19.5	3	-14
20.0	2	-15
20.5	1	-15
21.0	0	-16
21.5	0	-18
22.0	0	-20
22.5	1	-20
23.0	4	-18
23.5	4	-19
24.0	1	-32
24.5	12	-22
25.0	-10	-60
25.5	-12	0
26.0	- 2	50
26.5	12	75

Appendix A. (Continued)

V/R = .99 M246 Round

Time (sec)	WPEE (ɱ)	WPET (ɱ)
8.5	4	-24
9	4	-20
9.5	3	-16
10	1	-12
10.5	-4	-10
11	-4	- 8
11.5	-7	- 8
12	-8	-12
12.5	-8	-15
13	-7	-18
13.5	-7	-22
14	-4	-26
14.5	-4	-28
15	-7	-24
15.5	-9	-16
16	-8	- 8

V/R = .99 Hollow Round

Time (sec)	WPEE (ɱ)	WPET (ɱ)
8.5	8	- 4
9	8	- 4
9.5	8	- 6
10	9	- 7
10.5	7	- 8
11	8	- 9
11.5	7	- 8
12	7	- 6
12.5	6	- 4
13	7	- 7
13.5	7	-11
14	6	-16
14.5	4	-13
15.	1	-12
15.5	- 8	-26
16	-28	-42

Appendix A. (Continued)

V/R = .33 Caged Sight

Time (sec)	TEE (m/)	TET (m/)
2.5	0	1
3	0	-1
3.5	0	-1
4	-1	-2
4.5	-1	-2
5	-1	-2
5.5	0	-2
6	0	-2
6.5	-2	-2
7	-2	-2
7.5	-2	-2
8	-2	-2
8.5	-2	-2
9	-2	-2
9.5	-2	-1
10	-2	-1
10.5	-1	-1
11	-1	-1
11.5	-2	-1
12	-1	-1
12.5	-1	0
13	0	1
13.5	0	2
14	0	2
14.5	0	1
15	0	1
15.5	0	2
16	0	3
16.5	-1	3
17	-1	2
17.5	-1	1
18	0	2
18.5	0	3
19	-1	1
19.5	0	1
20	2	2
20.5	3	2
21	2	5
21.5	2	8
22	3	12
22.5	3	7
23	4	6

V/R = .66 Caged Sight

Time (sec)	TEE (m/)	TET (m/)
13.5	- 1	2
14	- 1	2
14.5	- 1	1
15	0	1
15.5	0	1
16	- 1	2
16.5	- 1	3
17	- 1	3
17.5	- 1	3
18	0	5
18.5	0	5
19	0	3
19.5	- 1	2
20	- 1	3
20.5	1	3
21	0	3
21.5	0	3
22	1	3
22.5	2	1
23	6	5
23.5	3	10
24	1	5
24.5	11	15
25	11	26
25.5	13	5
26	0	26
26.5	-29	5

Appendix A. (Continued)

V/R = .99 Caged Sight

Time (sec)	TEE (m)	TET (m)
8.5	-1	0
9	-1	1
9.5	0	1
10	-1	1
10.5	-1	2
11	0	4
11.5	0	2
12	-1	1
12.5	-1	1
13	0	1
13.5	[illegible]	5
14	1	10
14.5	0	8
15	2	5
15.5	0	1
16	7	5

Appendix A. (Continued)

V/R = .33 M246 Round

Time (sec)	Tee (ø)	TET (ø)
2.5	-2	-1
3	-2	-4
3.5	-1	-4
4	0	-4
4.5	1	-3
5	2	-2
5.5	0	-2
6	-1	-2
6.5	-2	-2
7	-3	-3
7.5	-3	-3
8	-3	-3
8.5	-3	-3
9	-3	-3
9.5	-3	-3
10	-2	-3
10.5	-2	-3
11	-2	-2
11.5	-2	-1
12	-2	-1
12.5	-3	-1
13	-3	-1
13.5	-3	0
14	-3	0
14.5	-2	1
15	-2	1
15.5	-2	1
16	-2	1
16.5	-2	1
17	-2	1
17.5	-2	1
18	-2	2
18.5	0	2
19	1	2
19.5	3	2
20	3	2
20.5	2	4
21	2	5
21.5	1	5
22	1	5
22.5	1	3
23	1	3

V/R = .33 Hollow Round

Time (sec)	TEE (ø)	TET (ø)
2.5	-2	-3
3	-4	-2
3.5	-1	0
4	-3	-1
4.5	-4	-2
5	-5	-2
5.5	-5	-2
6	-5	-2
6.5	-4	-2
7	-2	-2
7.5	0	-2
8	0	-3
8.5	0	-2
9	0	-3
9.5	-1	-2
10	-2	-1
10.5	-2	-1
11	-2	-1
11.5	-2	0
12	-2	0
12.5	-1	-1
13	-1	-1
13.5	0	-1
14	0	-1
14.5	0	0
15	0	1
15.5	0	3
16	0	4
16.5	0	3
17	0	2
17.5	0	2
18	0	2
18.5	1	3
19	1	3
19.5	3	4
20	3	4
20.5	1	5
21	-1	5
21.5	5	6
22	4	3
22.5	0	-5
23	-1	-9

Appendix A. (Continued)

V/R = .66 M246 Round

Time (sec)	TEE (ɱ)	TET (ɱ)
13.5	-6	- 3
14	-5	- 3
14.5	-4	- 2
15	-4	- 2
15.5	-4	- 1
16	-3	- 1
16.5	-3	0
17	-2	1
17.5	-2	1
18	-1	1
18.5	-1	1
19	-1	1
19.5	0	2
20	-1	3
20.5	0	4
21	0	5
21.5	0	3
22	1	2
22.5	5	0
23	6	- 1
23.5	8	1
24	7	9
24.5	4	12
25	6	11
25.5	8	20
26	2	25
26.5	-20	25

V/R = .66 Hollow Round

Time (sec)	TEE (ɱ)	TET (ɱ)
13.5	- 7	0
14	- 7	- 1
14.5	- 4	- 3
15	- 3	- 3
15.5	- 3	- 4
16	- 3	- 4
16.5	- 3	- 3
17	- 3	- 2
17.5	- 3	0
18	- 3	1
18.5	- 3	3
19	- 3	3
19.5	- 2	3
20	- 2	3
20.5	0	3
21	1	3
21.5	1	4
22	2	5
22.5	2	5
23	2	2
23.5	3	2
24	6	8
24.5	- 1	0
25	- 2	0
25.5	3	20
26	3	25
26.5	-13	25

Appendix A. (Continued)

V/R = .99 M246 Round

Time (sec)	TEE (₥)	TET (₥)
8.5	-5	4
9	-5	3
9.5	-4.5	2
10	-4	1
10.5	-3.5	0
11	-2.5	-1
11.5	-1.5	-1
12	-1.0	0
12.5	- .5	1
13	-1.0	2
13.5	-1.5	5
14	-2.0	7
14.5	-1.5	7
15	+1.0	5
15.5	+1.5	-1
16	+2.0	-9

V/R = .99 Hollow Round

Time (sec)	TEE (₥)	TET (₥)
8.5	-3	-4
9	-3	-4
9.5	-4	-3
10	-4	-2
10.5	-4	-1
11	-4	0
11.5	-4	-1
12	-4	-2
12.5	-4	-3
13	-5	-2
13.5	-5	2
14	-3	4
14.5	-2	3
15	-1	1
15.5	-4	-2
16	-5	-7

APPENDIX B

TABLE FOR MEAN AND STANDARD DEVIATION OF COMPONENT WEAPON POINTING AND TRACKING ERROR VERSUS V/R AND AMMUNITION

APPENDIX B.

TABLE FOR MEAN AND STANDARD DEVIATION OF COMPONENT WEAPON POINTING AND TRACKING ERROR VS. V/R AND AMMUNITION

Velocity Over Range Ratio (rad/sec)	V/R = .33			V/R = .66			V/R = .99		
Ammunition / Weapon Pointing & Tracking Error	M246	Hollow	Zero	M246	Hollow	Zero	M246	Hollow	Zero
WPEE (₥)	10.64	5.51	1.56	5.05	- 5.44	7.09	+ 4.55	9.37	2.90
WPET (₥)	3.86	4.34	3.14	32.70	23.85	6.62	+ 6.74	9.88	1.99
μ_{WPEE} (₥)	- 6.38	4.95	- .24	- 4.78	.11	.41	- 4.06	3.56	.313
μ_{WPET} (₥)	- 5.05	-3.35	.90	-22.44	- 9.44	5.4	-16.69	-11.44	3.0
TEE (₥)	1.86	2.23	1.56	5.65	3.89	7.09	2.20	2.38	2.90
TET (₥)	2.64	3.02	3.14	7.89	7.78	6.63	3.90	2.82	1.99
μ_{TEE} (₥)	- 1.10	- .76	- .24	- .37	- 1.56	.41	- 1.81	- 3.063	.313
μ_{TET} (₥)	- .29	-.024	.90	4.22	3.52	5.4	1.56	- 1.313	3.0

APPENDIX C

A COMPILATION OF READY TO FIRE LIGHT TIMES WITNESSED DURING THE TEST

APPENDIX C.

A COMPILATION OF READY TO FIRE LIGHT TIMES WITNESSED DURING THE TEST.

V/R = .33		V/R = .66		V/R = .99	
Ready to Fire Light On (sec.)	At Target 1900M. Range (sec.)	Ready to Fire Light On (sec.)	At Target 1900M. Range (sec.)	Ready to Fire Light On (sec.)	At Target 1900M. Range (sec.)
4 - 6	2.5	12 - 14	13.6	8 - 10	8.5

LIST OF SYMBOLS

$a_o \cdots a_n$	Constants (dimensionless)
ATD	Acquisition Time Delay
B	Small Correction Angle
$b_o \cdots b_n$	Constants (dimensionless)
CRT	Cathode Ray Tube
D	Slant Plane Range (M)
$D_o(t)$	Present Position Slant Plane Range
D_p	Future Position Slant Plane Range
e	2.7182818
Eg	Gun Elevation
Ego	Initial Gun Line Elevation
E_t	Elevation of Target
E_{to}	Initial Elevation of Target
H	Altitude of Target
K	Drag Coefficient
M	Meters
m̸	Army Mils
m/s	Meters per second
n	nth exponent
N	Number of Samples
Ø	Heading of the Target with Respect to X-axis(radians)
P_k	Probability of Kill
Q	Gravity Drop (M)
R	Ground Crossing Range

LIST OF SYMBOLS (Continued)

rad/s	Radians per second
R_E	Equivalent Ground Range
RMS	Root Mean Square
RSS	Root Sum Square Error
RTS	Radar Target Simulator
s	Superelevation Angle (ø)
SCG	Sight Current Generator
sec	Seconds
STP	Standard Temperature and Pressure
t	Time
TE	Radial Tracking Error
TEE	Elevation Tracking Error
TET	Train Tracking Error
T_F	Time of Flight
V	Velocity of Target
VADS-DFE	Vulcan Air Defense System - Dynamic Field Evaluator
V_m	Muzzle Velocity
V/R	Velocity over Ground Crossing Range
WPE	Radial Weapon Pointing Error
WPEE	Elevation Weapon Pointing Error
WPET	Train Weapon Pointing Error
W,Y,Z	Random Variables
X	Ground Range of the Target
μ_W	Mean Deviation

LIST OF SYMBOLS (Continued)

σ_w	Standard Deviation
Σ	Summation

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