AD720351

NWL TECHNICAL REPORT TR-[illegible]
November [illegible]

# THE NAVAL WEAPONS LABORATORY LASER RANGER/TRACKER SYSTEM

[illegible]

D D C
RECEIVED
MAR [illegible]
A

NAVAL WEAPONS LABORATORY
DAHLGREN VIRGINIA

NWL

[illegible]

52

NWL TECHNICAL REPORT TR-2469
November 1970

# THE NAVAL WEAPONS LABORATORY LASER RANGER/TRACKER SYSTEM

by

N. Norbert Harold

Distribution of this document is unlimited.

## ACKNOWLEDGEMENT

A good portion of the original design and development was completed by C. W. Brandts, L. J. Fontenot and R. A. Frazer, here at the Naval Weapons Laboratory, Dahlgren, Virginia. R. R. Humphries has been responsible for design refinements and for much of the installation and maintenance of the system's electrical and optical components as well as for operation of the system. A number of others have contributed to some extent and portions of this report have been extracted from the informal reports and studies of these people as well as the individuals mentioned above.

I am grateful to the Test and Evaluation Department, especially the Production Management Staff and the Operations Scheduling Office for their assistance in conducting the evaluation tests and the Motion Picture Section for assistance in obtaining documentary films of these test flights.

## ABSTRACT

A working breadboard model of a laser-based missile tracking and ranging system has been designed and developed by the Naval Weapons Laboratory, Dahlgren, Virginia. The system has been evaluated under actual range conditions where it has demonstrated its capabilities in tracking 2.75- and 5-inch rockets over the initial portion of their flights. Video tapes and color movies of these flights are available for inspection.

The system is a self-contained mobile unit containing several subsystems. Each subsystem is an independent unit in that it can be modified to meet specific requirements without affecting other subsystems. Sufficient flexibility is inherent in the system to render it useful as a research tool or as a standard range instrumentation item.

The system is now at the stage where further development will depend on potential user requirements. It is, therefore, requested that potential users submit their requirements to the Naval Weapons Laboratory to aid in determining future needs for the system.

## FOREWORD

This report describes a Laser Ranger/Tracker System which was conceived, designed, developed and constructed at the Naval Weapons Laboratory, Dahlgren, Virginia under Foundational Research and Independent Exploratory Development Funding. This system was developed in response to the need for a system that would yield accurate, reliable trajectory data during the burning period of small rockets having high energy and aluminized propellants; this data could not be obtained to the required accuracy with conventional radio-doppler systems. The purpose of this report is to define and describe system optics and electronics, system operation, operating procedures, system performance and capabilities achieved to date; to discuss projected capabilities, recommend future improvement action and encourage potential users to submit their requirements for such a system to the Naval Weapons Laboratory.

Released by:

R I Rossbacher

R. I. ROSSBACHER, Head
Engineering Department

## TABLE OF CONTENTS


| | Page |
|---|---|
| ACKNOWLEDGEMENT | i |
| ABSTRACT | ii |
| FOREWORD | iii |
| INTRODUCTION | 1 |
| WORKING MODEL SPECIFICATIONS | 1 |
| MAJOR SYSTEM COMPONENTS | 3 |
| OPTICAL COMPONENTS | 4 |
| OPTICAL TRACKING ANALYSIS | 6 |
| LASER RANGING ANALYSIS | 13 |
| TRACKING LOCATION AND TECHNIQUES | 15 |
| RESULTS | 25 |
| DATA SYSTEM | 31 |
| CONCLUSIONS, RECOMMENDATIONS AND FUTURE PLANS | 33 |
| REFERENCES | 34 |

ILLUSTRATIONS

**List of Figures:**

Figure 1 - Laser Ranger/Tracker System
Figure 2 - Top View - Laser Ranger/Tracker System
Figure 3 - Scannable Photomultiplier Tube
Figure 4 - Laser Tracking
Figure 5 - Photomultiplier Raster Rotation Device
Figure 6 - Laser Ranging
Figure 7 - Tracking Location

**List of Figures (Cont'd):**

Figure 8 - 2.75-Inch Rocket Launcher
Figure 9 - 5-Inch Rocket Launcher
Figure 10 - 2.75- and 5-Inch Rockets
Figure 11 - Rocket Lock-on Techniques
Figure 12 - Pick-off Technuque
Figure 13 - Production Pick-off Technique
Figure 14 - Rocket Tracking
Figure 15 - Proposed Data System

**List of Tables:**

Table 1 - Tracking Data

APPENDICES

A. Safety Analysis
B. Retroreflective Materials
C. Distribution

## INTRODUCTION

This system was developed in response to the need for a system that would yield accurate and reliable trajectory data during the burning period of small rockets having high energy, aluminized propellants which could not be obtained with conventional radio-doppler systems. Further, it would be of great value in research, development and test of new rockets, in preparation of improved range tables and in production testing of launchers and rockets.

This report presents a description of the Naval Weapons Laboratory experimental Laser Ranger/Tracker System (LRT).

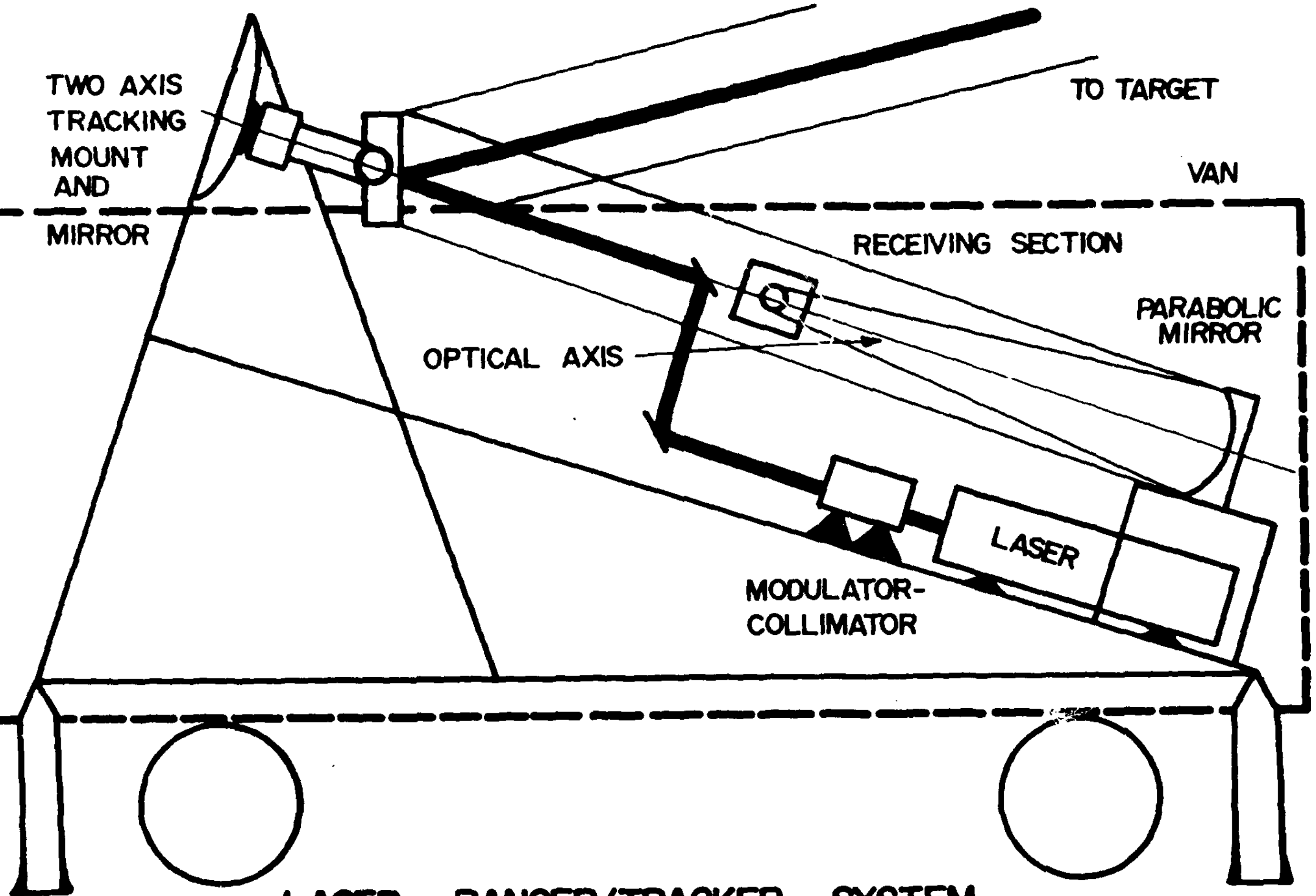
## WORKING MODEL SPECIFICATIONS

The LRT was designed as a development tool with provision for future system optimization and not as a pre-production prototype. It was designed such that substitutions or modifications of any of the subsystems could be readily accomplished without requiring extensive changes to the remaining subsystems, thus facilitating improvements to the system as new techniques and components become available.

The tracking mount has two degrees of rotational motion which we shall specify as azimuth and elevation. The azimuth mirror axis is the axis which is coincident with the system optical axis which is shown in Figure 1. The elevation mirror axis is the axis of motion which rotates about the azimuth axis and remains perpendicular to the azimuth axis at all times. The LRT is capable of tracking targets which do not require the system to exceed the following limits:

a. Elevation angular velocity of 2 radians per second.
b. Azimuth angular velocity of 3 radians per second.
c. Elevation angular acceleration of 4 radians per second per second.
d. Azimuth angular acceleration of 5 radians per second per second.
e. All combinations of "a" through "d" above.

The LRT is an automatic target tracking and ranging system having the capability of tracking cooperative targets and yielding video and motion picture coverage of the target being tracked.




LASER RANGER/TRACKER SYSTEM

FIGURE 1

The proposed data retrieval subsystem will record the following information: azimuth angle to ±0.5 milliradians; elevation angle to ±0.5 milliradians; range to ±1 foot; azimuth error to ±1/60 of the photomultiplier field of view, and time to ±100 microseconds. In addition, azimuth, azimuth error, elevation, elevation error and range will be sampled at the same time. This subsystem will have the capability of selecting any sampling rate from 10 to 200 samples per second depending upon the particular application.

## MAJOR SYSTEM COMPONENTS

A working model of the LRT system has been completed and assembled in a mobile trailer. Figures 1 and 2 illustrate the relative positions of the major components.

Among the components included are: an argon ion laser with 3.5 watts total output power; an electro-optical modulator for polarization modulating the beam; a beam expander; optical filters to minimize background light; a 16-inch diameter, 96-inch focal length parabolic mirror for focusing the return laser signal; a two-axis servo-driven mirror mount with a 17-inch flat pyrex mirror; a star tracking photomultiplier tube (PMT); a polarization analyzer, and a ranging PMT. Other important components include sample-and-hold amplifiers, PMT raster rotation device, auxiliary monitoring television and camera system and a data recording system.

The mechanical structure supporting the system is mounted at three points and is mechanically isolated from the vehicle housing. Support arms extend through holes in the side of the trailer and through the floor near the rear.

## OPTICAL COMPONENTS

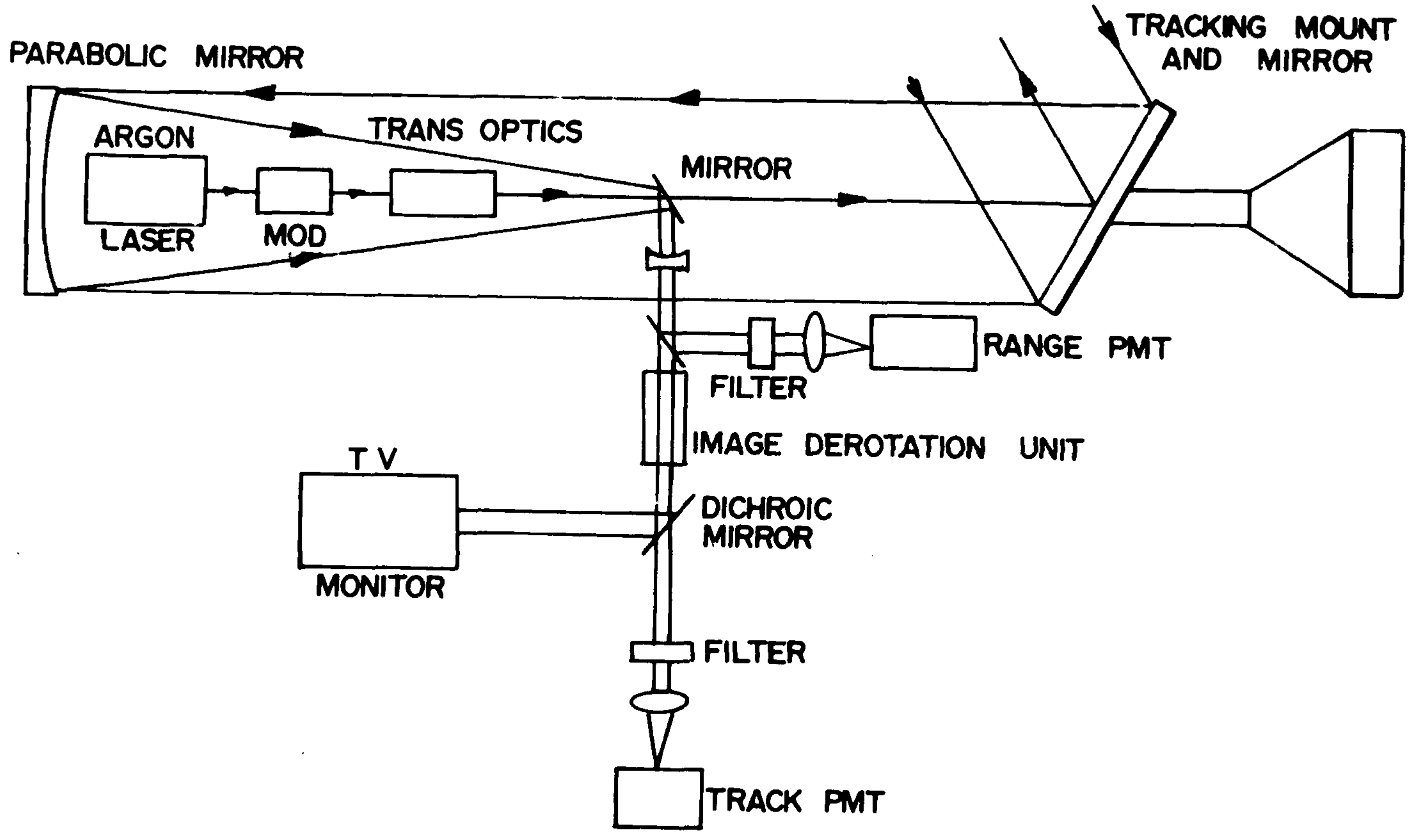
Figures 1 and 2 show how the transmitting and receiving functions of the LRT are accomplished. Large aperture reflective optics were chosen for the system to permit flexibility in the choice of any laser frequency in the infrared, visible or ultra-violet range for future modifications.

The two-axis, servo-driven tracking mount with its beam-directing mirror is the heart of the system since it serves to direct the transmitted laser beam and receives the retroreflected laser beam. This is accomplished by having a common transmitting and receiving axis. The tracking mount is positioned such that the axis of azimuth motion is coaxial with the optical axis of the parabolic mirror. This arrangement simplifies boresight alignment and eliminates parallax errors.

The pyrex beam directing mirror is 17 inches in diameter and 2 inches thick with the entire surface polished flat within one-half wavelength of Helium light with a regularity of one-quarter wavelength. The center two inches in polished flat within one-eighth wavelength with a regularity of one-sixteenth wavelength. The pyrex blank of the mirror is aluminized and overcoated with silicon dioxide to provide a reflectivity of 88% between 5000 and 9000 Å. The center portion of the mirror can withstand a continuous incident power density of 4100 watts per square centimeter.

The transmitting section of the LRT consists of an argon ion laser, mounted beneath the optical axis, which generates about 3.5 watts of continuous coherent radiation in the blue-green portion of the visible spectrum. This laser is used as the target illuminator. The laser beam passes through an electro-optical modulator where it is polarization modulated for target ranging. The beam then passes through transmitting optics which consists of an adjustable collimator and a remotely controlled shutter. Adjustment of the collimator determines the beam width or divergence of the transmitted signal. After shaping, the beam is brought up to the optical axis by two small front-surface beam directing mirrors and directed toward the servo-controlled flat mirror. The beam is then reflected from the servo-controlled flat mirror to the target being tracked.

The receiving section is essentially a Newtonian telescope. A portion of the transmitted beam is reflected from retroreflecting material mounted on the target, collected by the flat mirror and reflected down the optical axis to a 16-inch parabolic mirror. The parabolic mirror converges the beam back along the optical




TOP VIEW--LASER RANGER/TRACKER SYSTEM

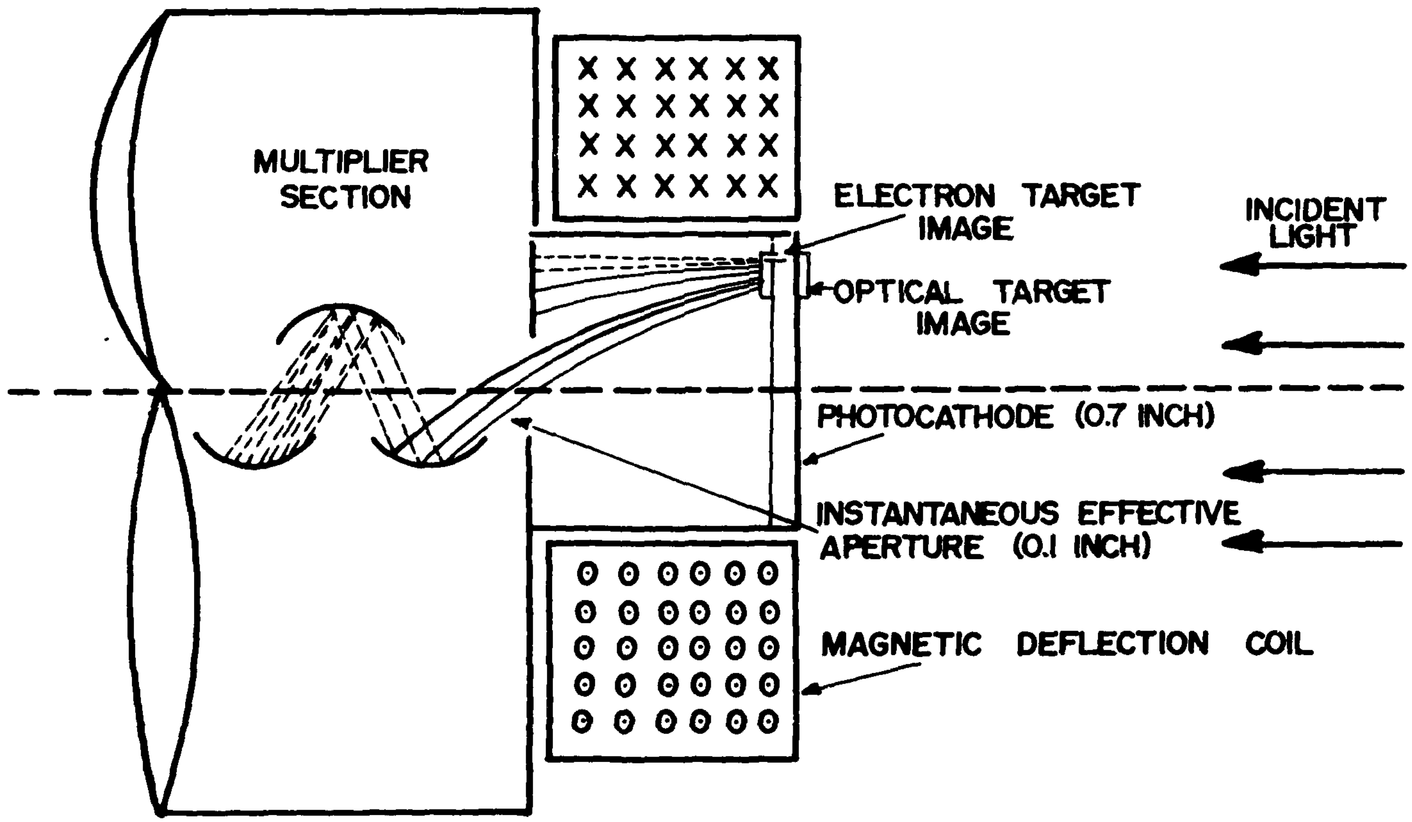
FIGURE 2

axis. Shortly before the beam reaches the focal point, a small fixed front-surface mirror takes the signal off-axis to a relay lens. The relay lens collimates the light into a three-quarter inch beam and provides the degree of collimation necessary for the use of spectral filters of very narrow bandwidth. After collimation the beam is split into two parts. One part goes through a PMT raster rotation device (discussed in next section) and dichroic mirror and is focused on the tracking PMT; the other portion goes through a narrow bandpass spectral filter and a polarization analyzer and is focused on the ranging PMT. The field of view of each photomultiplier tube is matched to the transmitted beam width by proper selection of focal lengths for the collimating and focusing lenses.

The dichroic mirror transmits the blue-green portion of the spectrum and reflects the remaining portion of the visible spectrum. The blue-green portion is used for tracking and the remaining portion is used for monitoring and recording the tracking operation on video tape and motion picture film.

## OPTICAL TRACKING ANALYSIS

Electro-optical tracking begins in the receiving section. Once the laser return signal passes through the PMT raster rotation device an image is formed on a scannable PMT which with its associated circuitry generates target position error signals (Figure 3). Incident photons release electrons from the photocathode surface. These electrons are accelerated toward the multiplying section of the PMT. The electron paths are curved in response to the magnetic field generated by the deflection coils. Thus the electron image of the photocathode is swept across the instantaneous effective aperture. This is equivalent to saying that the 0.7-inch photocathode is itself scanned by the 0.1-inch aperture. The intensity of the magnetic field is proportional to the current flowing through the deflection coil. An appropriate series resistor provides a voltage which is proportional to the deflection current, the intensity of the magnetic field, and hence the position of the instantaneous effective aperture in its scan along the photocathode surface. Should the image of a laser illuminated target appear on the face of the photocathode, its electron image will be sensed by the multiplying section only when the magnetic field is of proper value to bring the image into the aperture. The voltage across the series resistor at that instant in time will give the relative position of the target from the central optic axis.



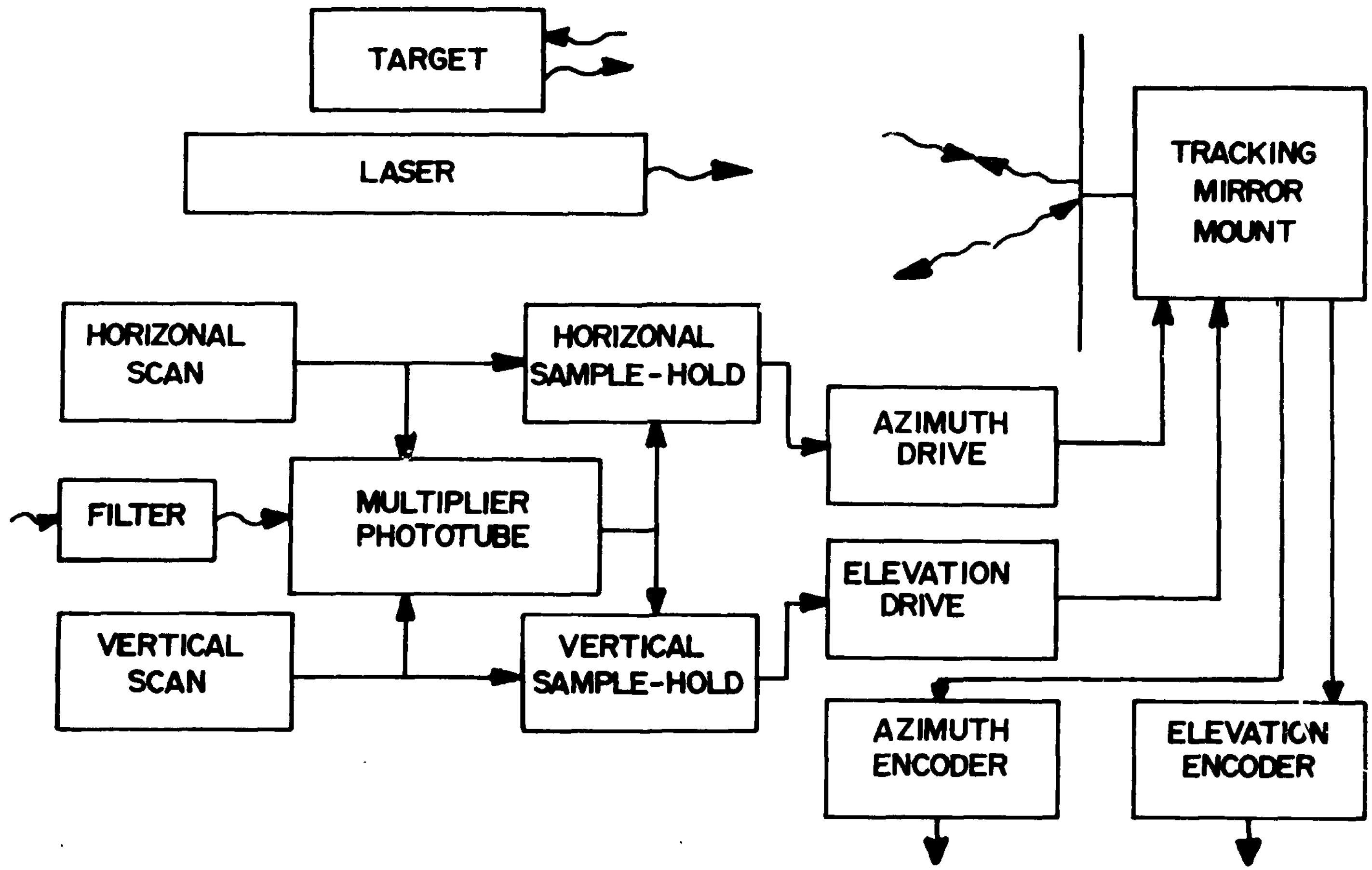

**SCANNABLE PHOTOMULTIPLIER TUBE**

FIGURE 3

The photocathode is scanned at a 20-kilohertz rate horizontally and at a 3-kilohertz rate vertically. When the image of the laser illuminated target is scanned across the aperture a pulse is generated by the photomultiplier tube. This pulse activates the sample mode of the sample-and-hold amplifiers which sense the position offset voltages of the deflection coils, (Figure 4). When the scanning aperature moves off-target the sample-and-hold modules revert to the hold mode retaining voltages corresponding to the position at which the target last appeared. These voltages, representing horizontal and vertical target position errors, are applied to the servo amplifiers which drive the elevation and azimuth torque motors of the tracking mount in a direction that will reduce the error signals toward zero (recentering the image on the photocathode of the tracking PMT). If the image is in the center of the photomultiplier tube, no corrections are necessary.

This method of obtaining error signals for optical tracking is relatively independent of target range and signal strength. It will also compensate for intermittent loss of target since the sample-and-hold amplifiers will retain their last detected voltage for 300 milliseconds or until a new signal activates the sample mode. The tracking mount will continue moving in the same direction and at the same speed until the target reappears or until the 300 milliseconds have elapsed at which time the system drops out of the track mode.

Going back for a moment, let us discuss the function of the PMT raster rotation device (PMT RRD). We will assume that there is no PMT RRD and consider what happens in the receiving system. When the PMT is aligned for optimum tracking of a stationary target the axes of an imaginary coordinate system on the fact of the PMT through the center of the square scanning raster is aligned with the axes of an imaginary coordinate system on the face of the tracking mirror. When the stationary target is permitted to move throughout its trajectory the system moves off its optimum tracking position causing the tracking mirror coordinate system to rotate with respect to the PMT coordinate system. Misalignment of the two coordinate systems readily degrades the tracking ability of the LRT until the target is finally lost at a 40 degree tracking angle. The tracking PMT converts the target image position on its photocathode relative to its coordinate system into azimuth and elevation error signals. Since the coordinate system of the tracking mirror has rotated about the system's optical axis (azimuth) the error signal generated by the PMT will be incorrect with respect to the tracking mirror coordinate system thereby driving the tracking mirror in the wrong direction. Tracking mirror coordinate system rotation is limited to a function of azimuth




LASER TRACKING

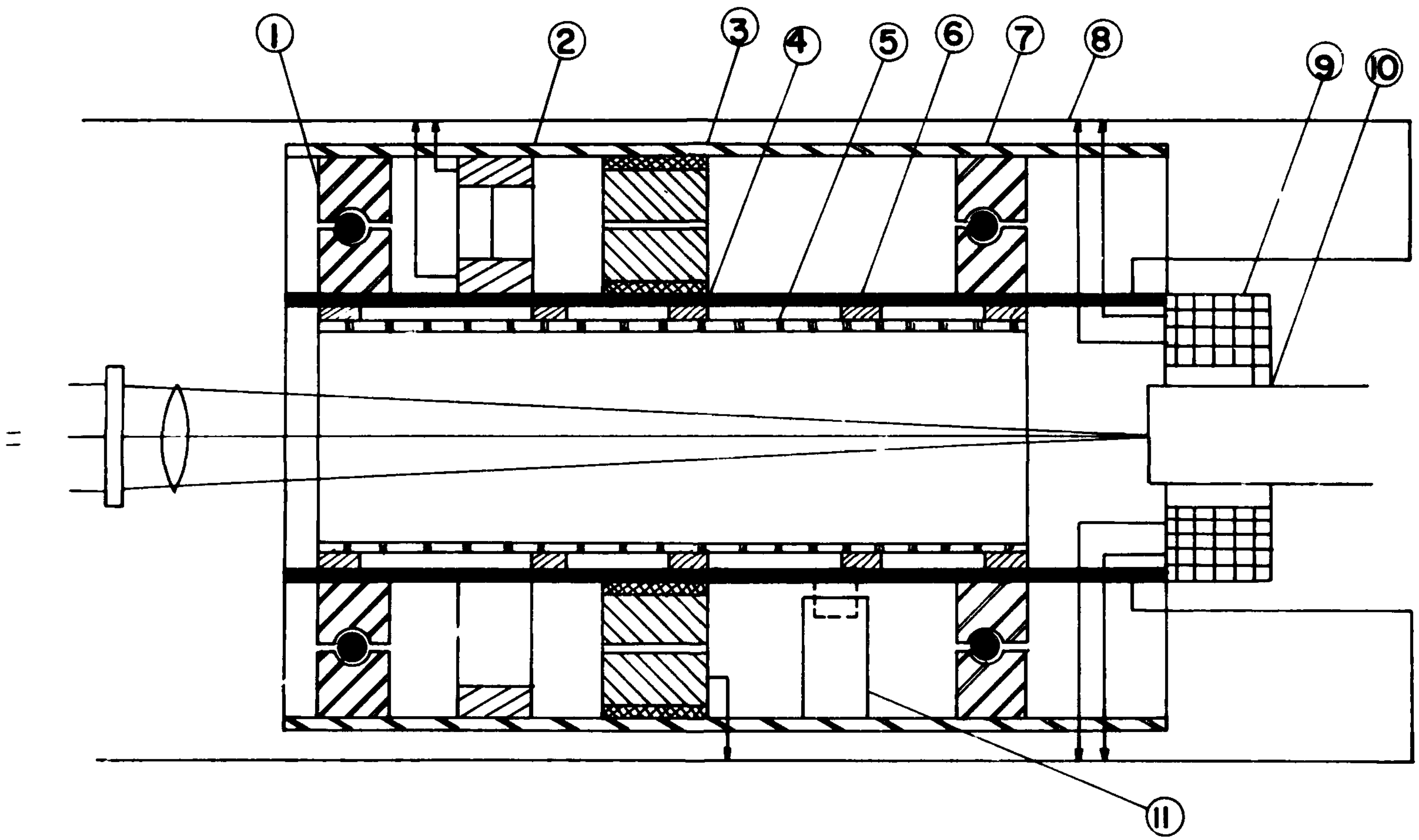
FIGURE 4

motion only since in this design the system's optical axis is always perpendicular to the axis of elevation motion. If this problem were to go uncorrected the system would be limited to small azimuth tracking angles.

To eliminate misalignment of the two coordinate systems the PMT raster coordinate system must be slaved to the azimuth axis of the tracking mirror which will allow the two coordinate systems to rotate together and remain in alignment.

Two methods of rotating the PMT raster coordinate system, one mechanical and the other electrical, have been developed. The mechanical unit shown in Figure 5 consists of a torque motor, bearings and a potentiometer rigidly attached to a two-inch tubular shaft. The tubular shaft is then rigidly attached to the deflection yoke of the tracking PMT. The torque motor is slaved to the azimuth axis of the tracking mount. Therefore, as the tracking mount coordinate system rotates in azimuth, the torque motor receives a signal which causes it to rotate the deflection yoke a corresponding amount in the same direction. Rotation of the deflection yoke causes the raster coordinate system to rotate a corresponding amount. Since the PMT raster coordinate system and the tracking mount coordinate system rotate together, the image rotation problem is solved. This method of rotating the deflection yoke is equivalent to rotating the entire PMT but much simpler to achieve.

The second method, which is electronic, accomplishes the same task as described above, except the PMT and deflection yoke remain stationary while the phases of the two deflection coils' currents are changed, using an electrical synchro-resolver, so as to electronically rotate the PMT raster coordinate system the required amount. Here again the resolver is slaved to the azimuth axis of the tracking mount causing the mount coordinate system and the PMT raster coordinate system to rotate together.




**PHOTOMULTIPLIER RASTER ROTATION DEVICE**

FIGURE 5

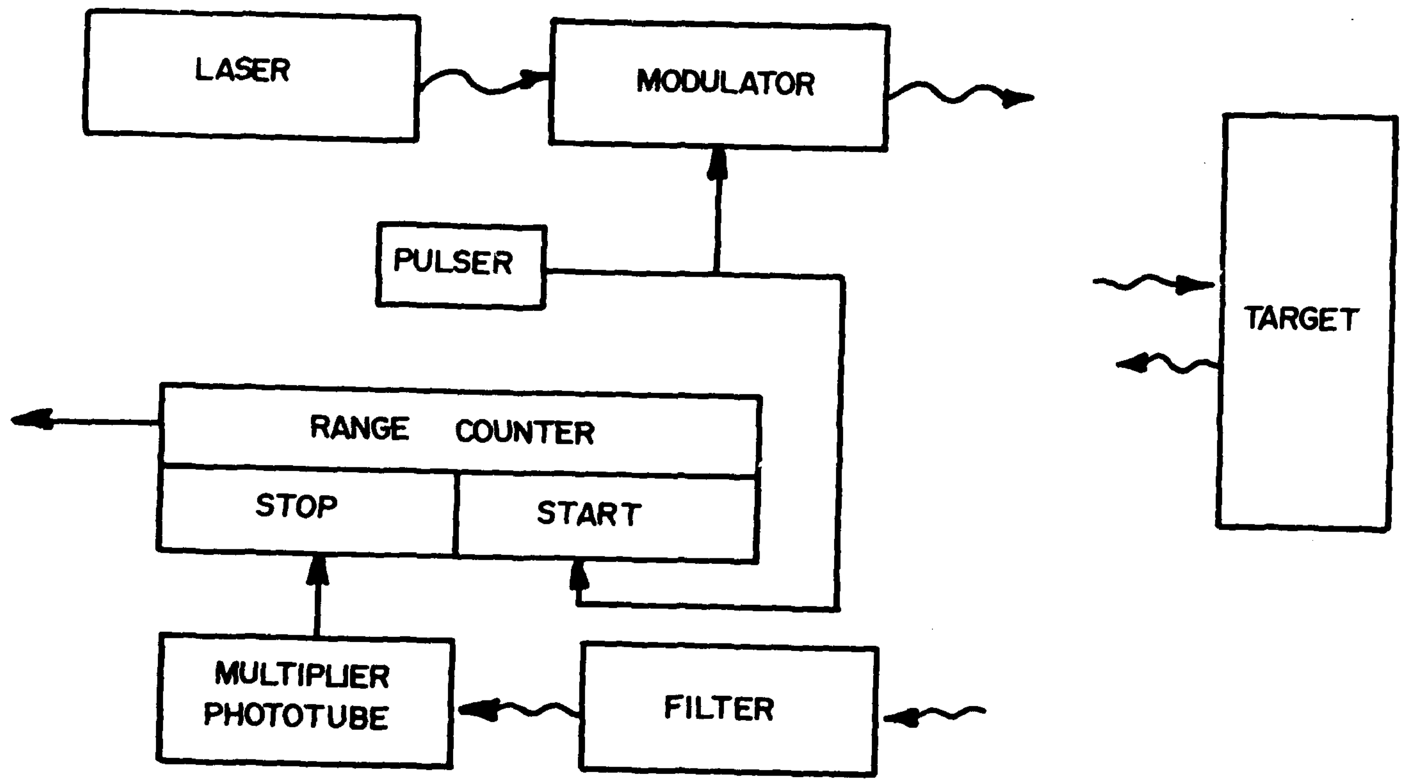
1. Ball Bearing
2. Potentiometer
3. Torque Motor
4. Rubber Gasket
5. Shielding
6. Rotating Cylinder
7. Stationary Cylinder
8. Light Shield
9. Deflection Coil
10. Photomultiplier Tube
11. Overdrive Stop

## LASER RANGING ANALYSIS

The ranging section is diagramed in Figure 6. The transmitted laser beam passes through an electro-optical modulator which changes the angle of polarization when a voltage is applied to it. The modulator is electronically pulsed at a repetition rate of 3,000 per second. The same pulse is also used to start a range (time interval) counter. The laser beam is then directed toward the target by the mirrors previously described. The return beam reflected from the target passes through the receiving optics to a polarization analyzer which is aligned to pass the pulse which is detected by a photomultiplier tube. The optical signal received by the photomultiplier tube generates an electrical pulse which stops the counter. The distance of the target is directly proportional to the elapsed time. The present counter reads out directly in feet.

There are two significant advantages to using polarization modulation rather than amplitude modulation for laser ranging. One advantage is that there is no dead time. Due to the nature of amplitude modulation there is a relatively long period of time that the beam is off or at low level transmission (dead time). There is a finite probability that this will occur during a critical scan interval, i.e., when the tracking PMT is viewing the target. Using polarization modulation, continuous tracking capabilities are greatly improved since the tracking tube is insensitive to a shift in polarization angle. The second important feature of polarization modulation for ranging is a large increase in signal to noise ratio. The analyzer in front of the ranging PMT may be adjusted to inhibit the preferred polarization planes of ambient radiation.

The system is calibrated by ranging on a target of known distance from the tracking site. The difference between the measured and calculated time required for pulse travel is the electrical delay time which consists of the time required for light and electrical signals to travel within the transmitting, receiving and detection systems. It also includes the delay time resulting from the finite rise time of the modulated signal. The primary limiting factors on ranging accuracy are the electrical rise time of the light modulator and pulse shape deterioration from various causes. The lithium niobate crystal has an electrical rise time of nearly 10 nanoseconds, corresponding to a distance of about 5 feet (worst case).




LASER RANGING

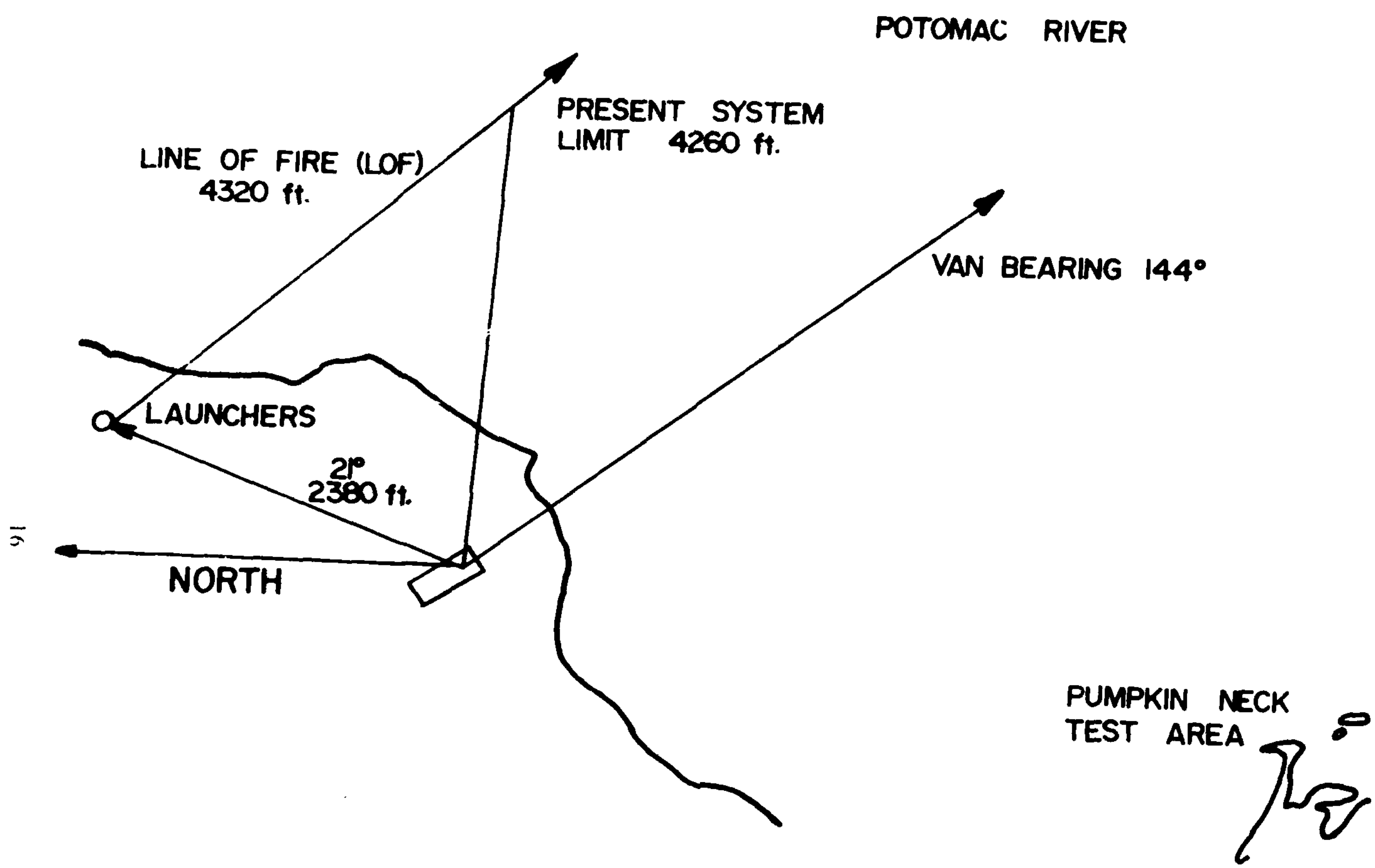
FIGURE 6

## TRACKING LOCATION AND TECHNIQUES

Three basic requirements must be met when tracking rockets with this system. First, there must be a clear, unobstructed line of sight between the LRT and the rocket at all times throughout the flight path. Second, the rocket must be cooperative, i.e., it must display some type of retroreflective material to enhance the return signal. Third, there must be a lock-on procedure prior to launching the rocket. In addition to a clear line of sight, a section of the rocket body must remain visible to the LRT at all times. A corner cube is not practical for this application: hence we used a 3-inch strip of #7610 Scotchlite Brand High Reflectance Sheeting manufactured by 3M Company which is discussed in Appendix B. The possibility of tracking from behind the launcher is ruled out due to the lack of an appropriate target reflecting area on the rear end of the rocket. Ideally the tracker should be located near the midpoint of the rocket path and at some distance away; the minimum distance depends upon the angular rates of the target with respect to the LRT. In relation to the NWL range, the ideal location would be on the Pumpkin Neck shore line as shown in Figure 7. However, for initial evaluation purposes we chose a tracking location at the Main Battery, 2,380 feet from the rocket launchers as shown in Figure 7. The site was chosen for several reasons including availability of utilities (power and water) and safety, i.e., the area is closed off during rocket firing eliminating the chance of exposure of personnel to the laser beam.

The requirement for a retroreflective material on the rocket to enhance the return signal is currently being met by using a material identified as #7610 Scotchlite Brand High Reflectance Sheeting manufactured by 3M Company. A retroreflective material rather than reflective material must be used since the beam must return along its transmitted path. Rockets are prepared by placing a three-inch strip of the sheeting around the warhead. When tracking production acceptance test rockets the use of any material other than paint on the rocket is prohibited; therefore, we are actively working with the 3M Company to develop a practical retroreflective paint suitable for tracking purposes.

Figure 8 shows the launcher used to fire 2.75-inch rockets at the NWL range. This launcher has no MARK and MOD designation, as it was specially built for NWL production testing. Figure 9 shows the MARK 102 MOD 0 launcher used to fire 5-inch spin-stabilized rockets. Figure 10 shows the 2.75- and 5-inch rockets that were tracked. The following is a comparison of the characteristics of these two rockets:




TRACKING LOCATION

FIGURE 7

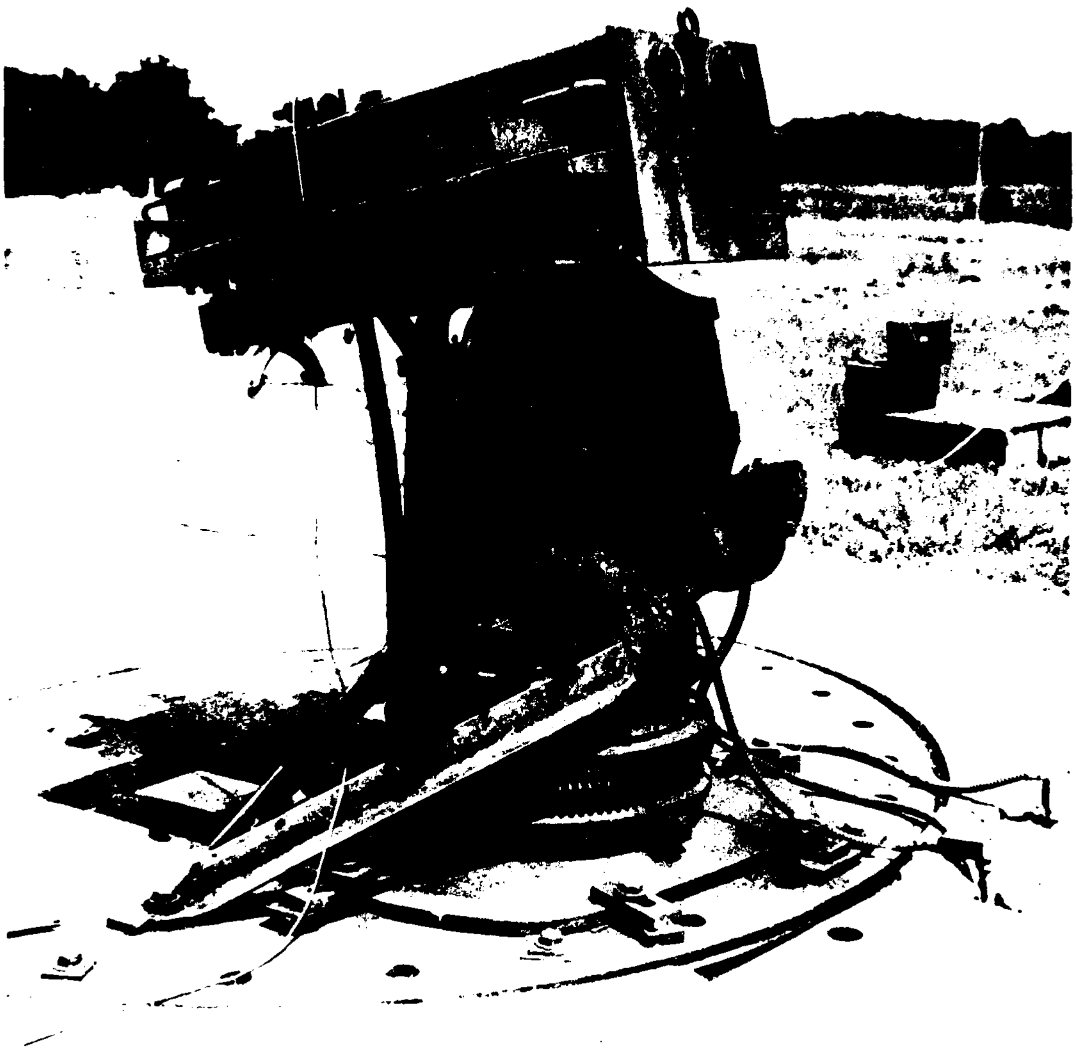


FIGURE 8

2.75-INCH ROCKET LAUNCHER

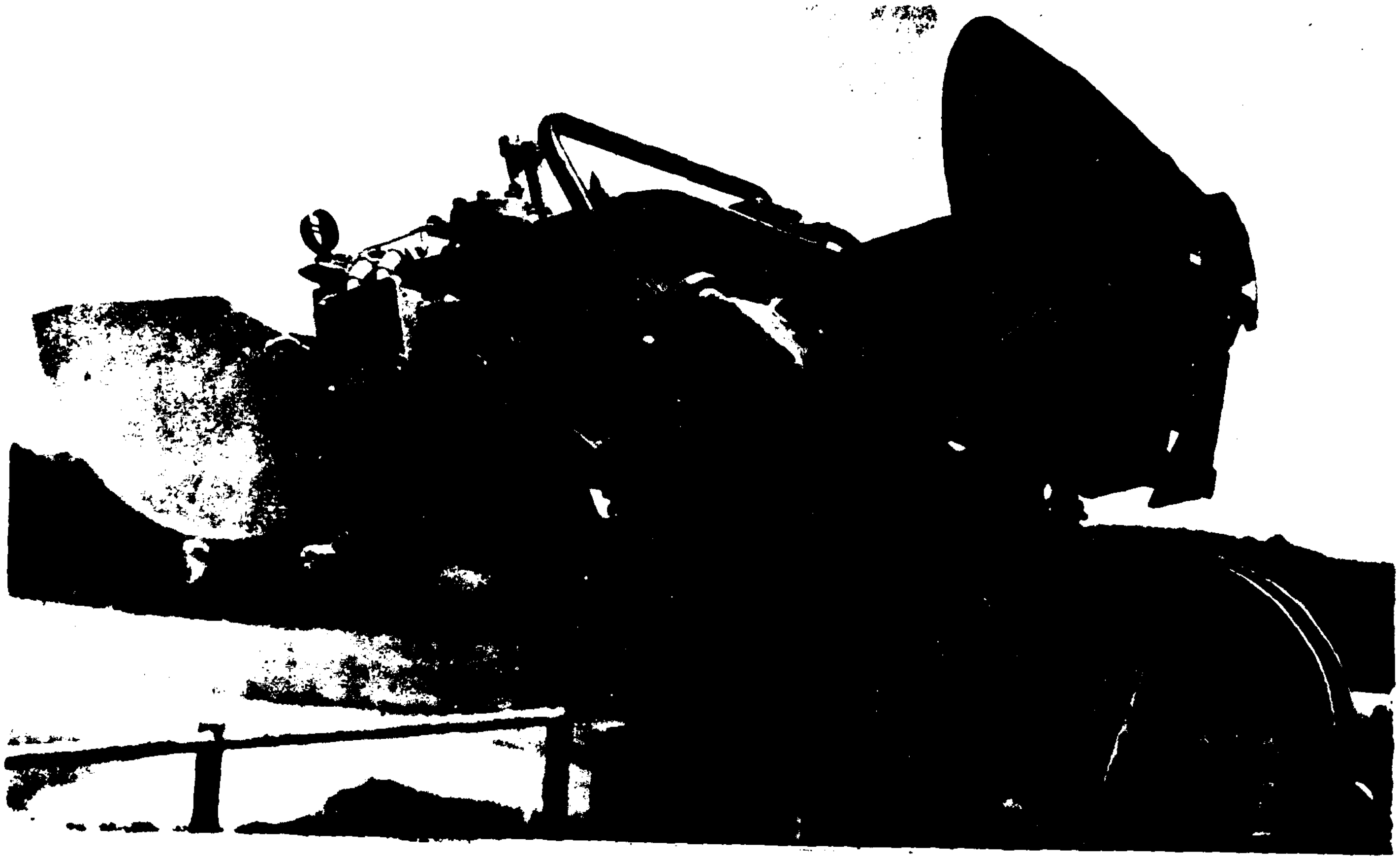


FIGURE 9

5-INCH ROCKET LAUNCHER

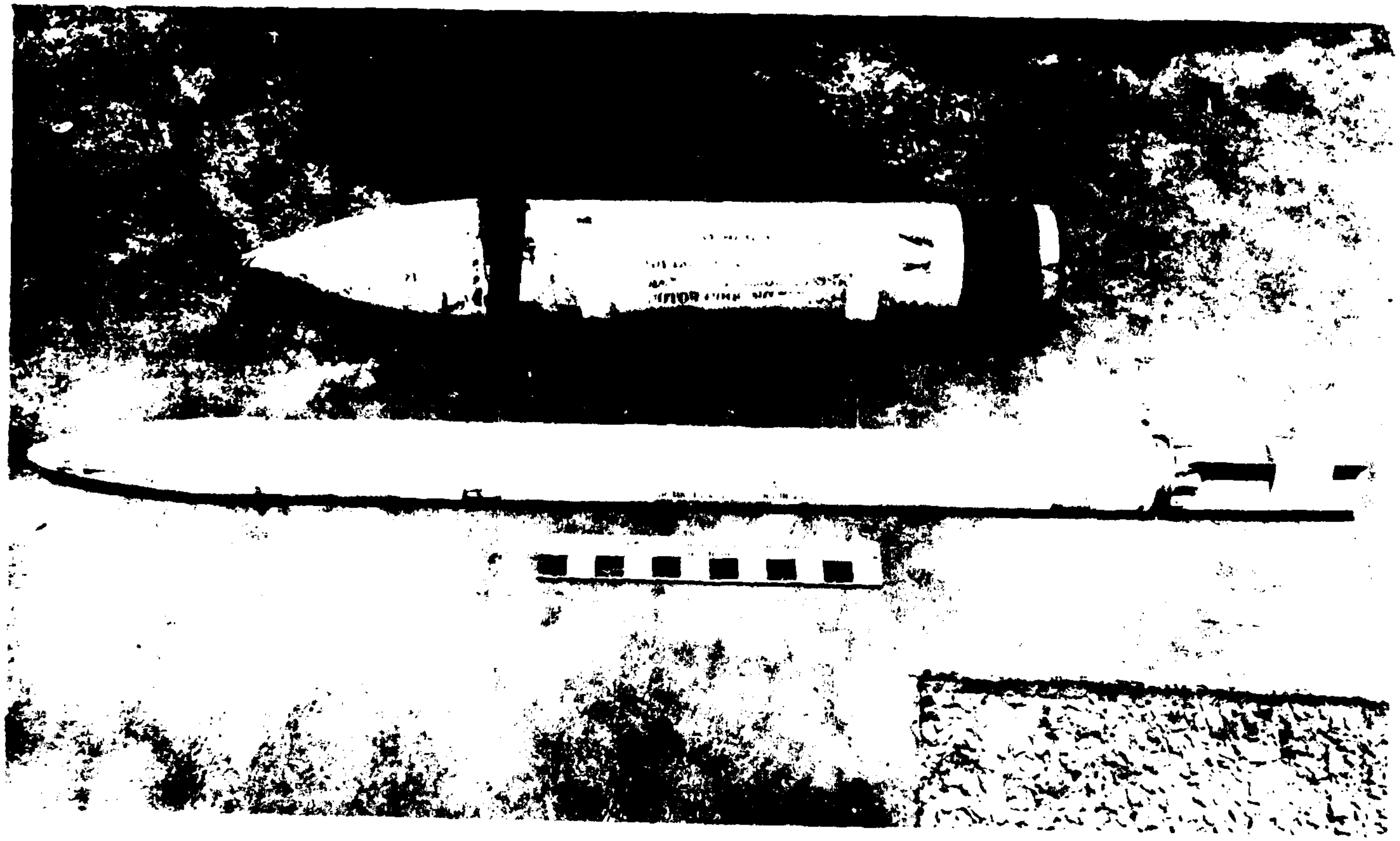


FIGURE 10

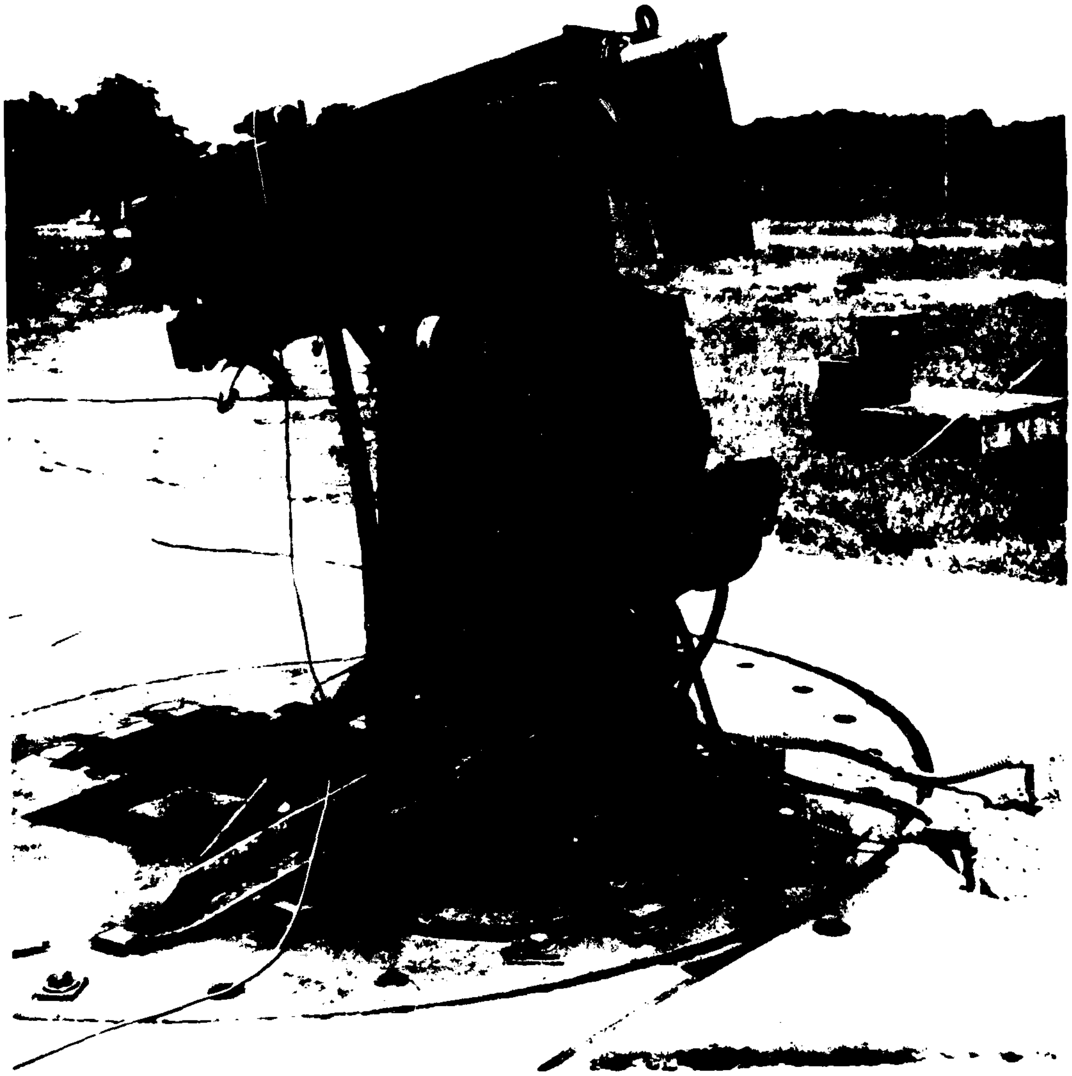
2.75- AND 5-INCH ROCKETS

| **2.75-Inch, Folding Fin Rocket** | **5-Inch, Spin-Stabilized Rocket** |
|---|---|
| Motor - MARK 40 MOD 3<br>MARK 4 MOD 10 | Motor - MARK 3 MOD 4 |
| Angle of fire - 13° | Angle of fire - 13.20° |
| Max. Range (at 13°) - 6500 yds. | Max. Range (at 13.20°) - 550 yds. |
| Burn Time - 0.80 Sec. | Burn Time - .93 sec. |
| Average Velocity - 1800 ft/sec.<br>(first 3 sec.) | Average Velocity for (first 2 sec.)<br>950 ft/sec. |
| | Flight Time - 17.45 sec. |

In order to track these rockets, they must first be acquired by the system. Two techniques have been used to acquire and lock on to the rockets. The procedure for the first method is to load the specially prepared rocket into the launcher with the warhead extended as shown in Figure 11. The system is then placed in the manual mode and the tracking mirror positioned so as to direct the laser beam to the exit port of the rocket launcher. The system is then placed in the acquisition mode causing the system to lock on the warhead. The rocket is then fired and tracked. The second method is similar to the first with some exceptions. The rocket launcher has two tubes side-by-side. In the tube nearest the LRT the rocket to be tracked is inserted in normal fashion leaving none of it exposed. A dummy round is inserted in the second tube with warhead exposed. The beam is then directed and locked on the dummy round. As the rocket to be tracked is fired it emerges from the launcher and interrupts the beam as shown in Figure 12. As soon as the rocket interrupts enough of the beam the system will lock on the moving rocket and begin tracking it. This procedure has been dubbed "pick-off".

Tracking of production acceptance test rounds could be accomplished using the pick-off technique. Instead of using a dummy round, a small retroreflective target could be placed directly behind the exit port of the launcher and used to lock the system on as illustrated in Figure 13. Both launcher tubes can be loaded with specially prepared rockets to be fired and tracked sequentially using the procedure described above.

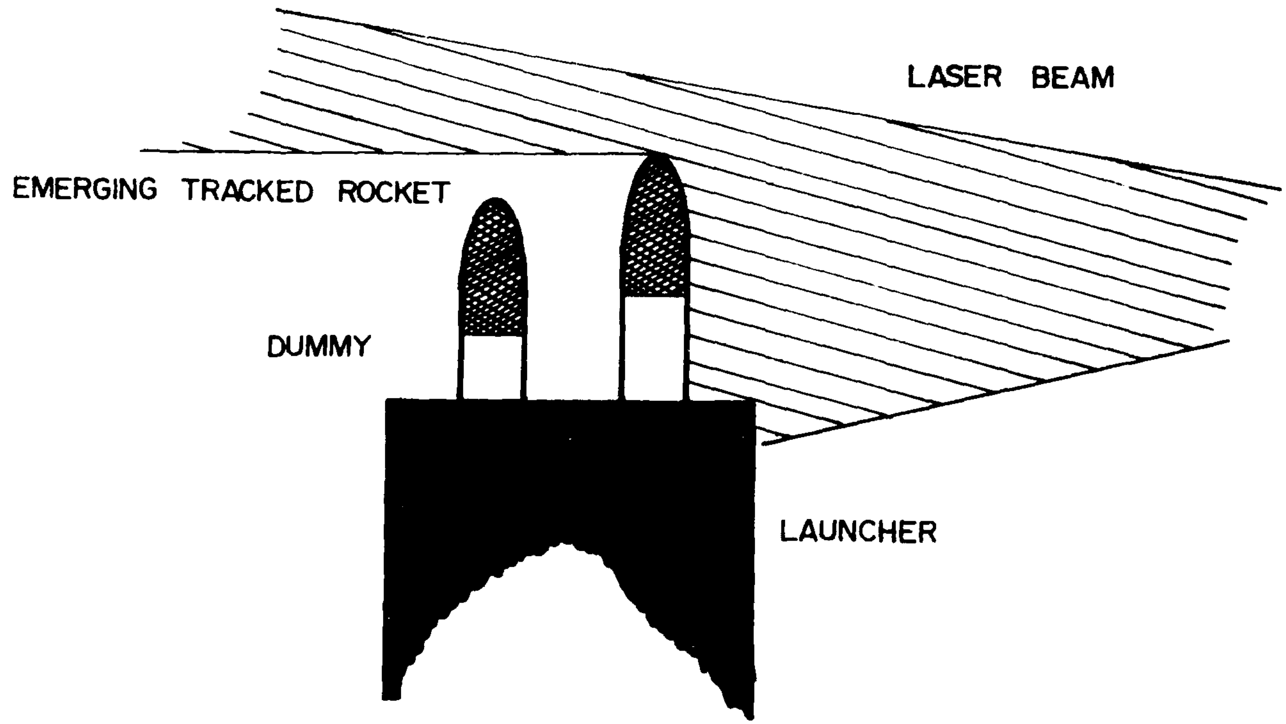
The system also has an auto-track capability which functions in the following manner. The operator must first position the tracking mirror so as to direct the beam to the target area. This is accomplished by using the manual mode. The



NOT REPRODUCIBLE

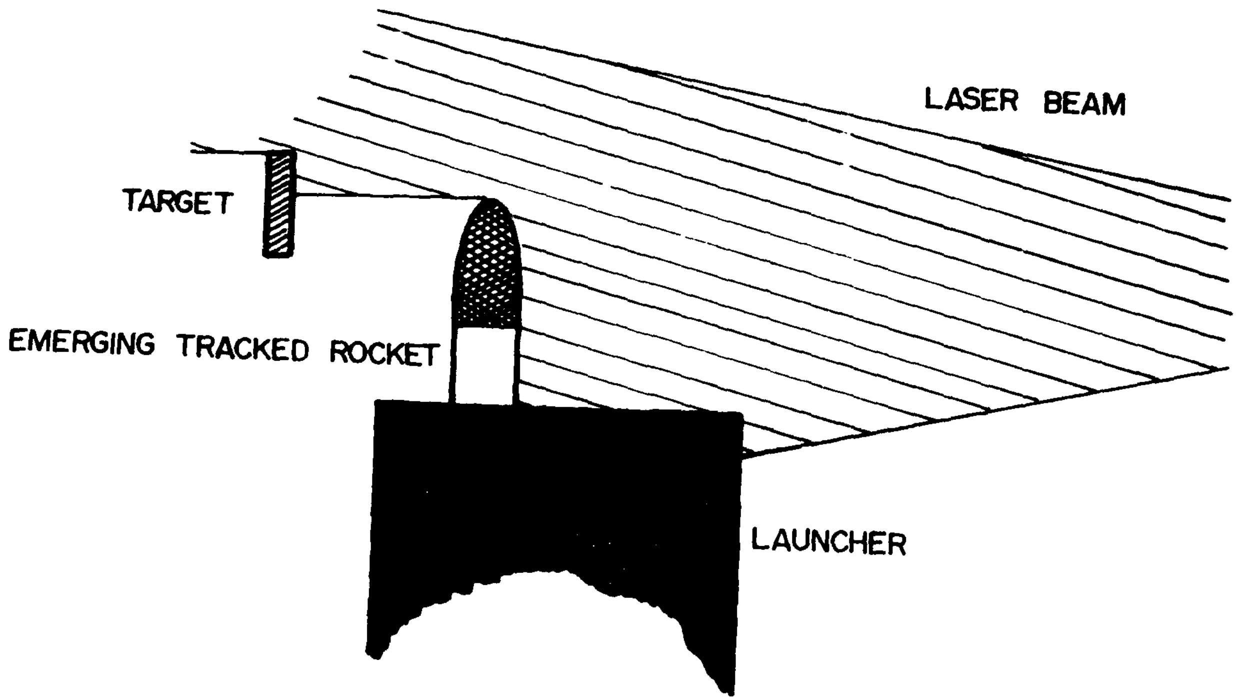
FIGURE 11

ROCKET LOCK-ON TECHNIQUE




**PICK-OFF TECHNIQUE**

FIGURE 12




PRODUCTION PICK-OFF TECHNIQUE

FIGURE 13

system is then placed in the auto-track mode causing the system to lock on the rocket or target if the pick-off technique is used. The rocket is then fired and tracked. Upon losing the rocket, the auto-track mode returns the tracking mirror to its initial position at the target area where it automatically locks onto the next round or target. Once the initial target area is defined, the LRT will continue to track rockets indefinitely (as long as it is in the auto-track mode) without assistance of the operator.

With this option production test rounds can be fired and tracked at an extremely fast rate.

## RESULTS

Table 1 represents preliminary data obtained from the 20 specially prepared rockets fired at the NWL range for LRT evaluation purposes. These data, presented in six categories, represent results of both the 2.75- and 5-inch rockets. The row labeled mirror angle represents the azimuth and elevation angle through which the normals to the two-axis tracking mirror move while tracking the rocket from launch to the point in space where the rocket was lost. The angle labeled $\beta$ in Figure 14 represents the mirror angle in one plane. These data were obtained from potentiometers attached to the moving axes and recorded on a light beam galvanometer direct-writing oscillograph. These angles could be referenced to a common point such as the system optical axis if desired by adding the angle $\alpha$ in Figure 14 to $\beta$. For evaluation purposes this has not been done.

The data representing tracking angle are the azimuth and elevation angles through which the rockets were actually tracked from the launch point. The angle labeled $\gamma$ in Figure 14 illustrates these angles in one plane. This information was also obtained from the potentiometers and oscillograph and in all cases is twice the mirror angle.

The maximum distance is presented in terms of launcher to target and tracker to target. The launch to target distance represents the distance the target traveled from the launcher before it was lost as illustrated in Figure 14 by the distance marked L. The tracker to target distance is the distance from the tracker van to the point in space where the target was lost represented by D + $\Delta$D in Figure 14. For these tests a high-speed motion picture camera was placed in the position normally occupied by the ranging photomultiplier tube so that documentary motion pictures could be taken through the entire system optics. Therefore these distances are theoretical values calculated by using the tracking angle and assuming a straight line of flight. Since these distances were calculated rather than measured these may be slight errors involved, however all data are consistent and it must be remembered these data were obtained for evaluation purposes only.

From Figure 14 it can be seen that the orientation of the system would limit the tracking angle. Since the PMT RRD was not installed during these tests, it was necessary to situate the system in a manner that would minimize the azimuth tracking angle. Even with this orientation however, azimuth rotation was the principal factor limiting maximum distance.

**TABLE 1**

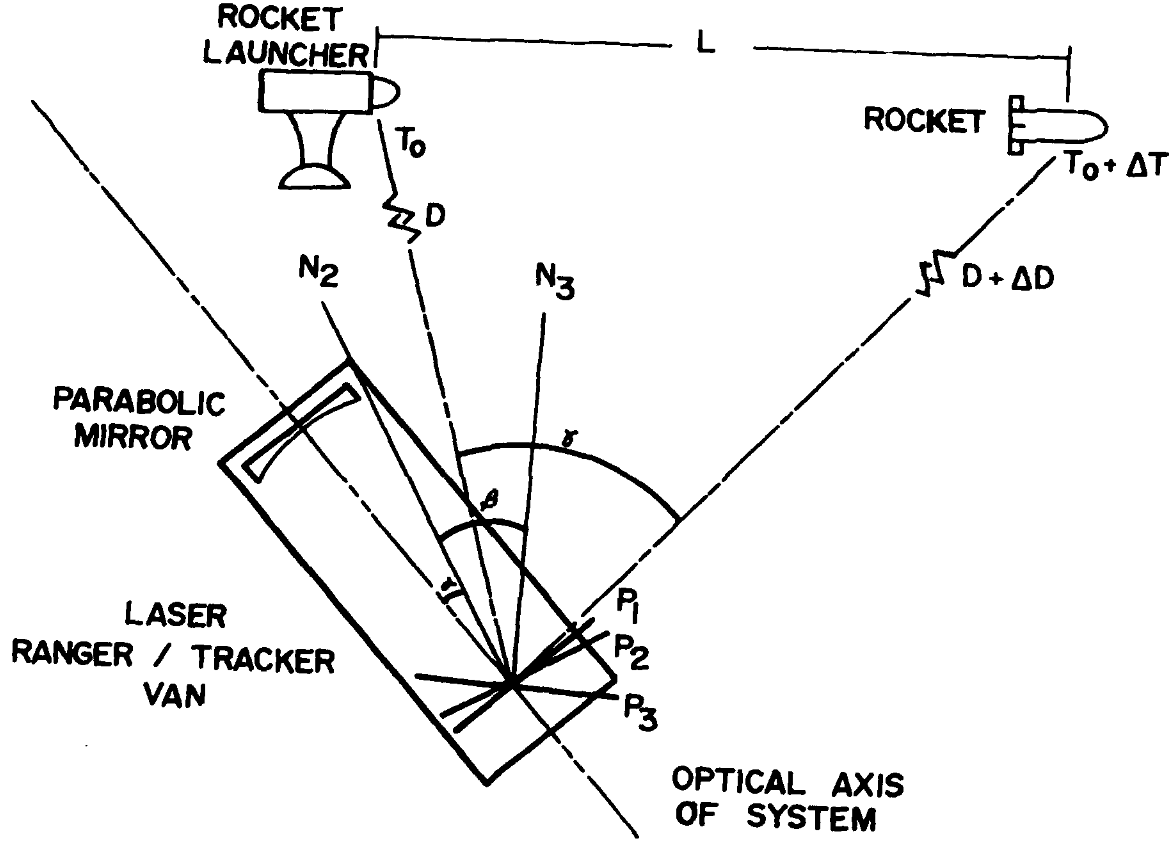
**TRACKING DATA**

**2.75 FOLDING FIN ROCKETS**

| Rocket Number | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MIRROR ANGLE | AZIMUTH (Deg.) | 14.7 | R | 19.2 | 1.40 | 17.0 | 25.0 | 21.0 | 11.7 | 8.8 | 6.1 |
| | ELEVATION (Deg.) | 36.9 | A | 31.8 | 1.20 | 32.9 | 26.4 | 32.5 | 34.5 | 35.4 | 35.8 |
| TRACKING ANGLE | AZIMUTH (Deg.) | 29.4 | D | 38.4 | 2.70 | 34.0 | 50.0 | 42.0 | 23.4 | 17.6 | 12.2 |
| | ELEVATION (Deg.) | 73.8 | A | 63.6 | 2.30 | 65.8 | 52.8 | 65.0 | 68.8 | 70.8 | 71.6 |
| MAXIMUM DISTANCE | LAUNCHER (Ft.) TO TARGET | 4050 | R | 4070 | 610. | 3650 | 3420 | 4320 | 3980 | 3960 | 4140 |
| | TRACKER (Ft.) TO TARGET | 4030 | I N T | 4200 | 2160 | 3710 | 3530 | 4400 | 3970 | 3960 | 4140 |
| MAXIMUM VELOCITY | AZIMUTH rad sec | 0.19 | E R | 0.21 | 0.15 | 0.12 | 0.19 | 0.15 | 0.22 | 0.15 | 0.11 |
| | ELEVATION rad sec | 0.54 | F E R E | 0.42 | 0.56 | 0.49 | 0.41 | 0.42 | 0.46 | 0.48 | 0.55 |
| MAXIMUM ACCELERATION | AZIMUTH rad sec$^2$ | 0.45 | N C E | 0.36 | 0.46 | 0.60 | 0.47 | 0.46 | 0.60 | 0.48 | 0.36 |
| | ELEVATION rad sec$^2$ | 0.85 | | 0.81 | 0.80 | 0.80 | 0.92 | 0.81 | 0.91 | 0.91 | 0.74 |
| TRACK TIME | SECONDS | 2.25 | | 2.26 | 0.34 | 2.03 | 1.90 | 2.40 | 2.21 | 2.20 | 2.31 |

**TABLE 1 Cont.**
**2.75 FOLDING FIN ROCKETS**

| | | | | | | | | | 5-Inch Spin Stabilized Rocket | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rocket Number** | | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** |
| MIRROR ANGLE | AZIMUTH (Deg.) | PAINTED | 8.20 | 10.5 | 9.00 | COMMUNICATIONS | 13.6 | 10.2 | OPTICAL | 7.50 | 8.61 |
| | ELEVATION (Deg.) | | 28.3 | 33.2 | 34.1 | | 25.7 | 23.7 | | 21.8 | 24.7 |
| TRACKING ANGLE | AZIMUTH (Deg.) | | 16.4 | 21.0 | 18.1 | | 25.4 | 22.6 | | 15.0 | 16.3 |
| | ELEVATION (Deg.) | | 56.6 | 66.4 | 68.2 | | 51.8 | 50.7 | | 43.6 | 40.4 |
| MAXIMUM DISTANCE | LAUNCHER (Ft.) TO TARGET | PICK OFF | 3600 | 3690 | 3910 | | 3620 | 3540 | INTERFERENCE | 1800 | 2100 |
| | TRACKER (Ft.) TO TARGET | | 3670 | 3740 | 3910 | BREAK DOWN | 3705 | 3690 | | 2500 | 2650 |
| MAXIMUM VELOCITY | AZIMUTH rad/sec | | 0.15 | 0.18 | 0.13 | | 0.16 | 0.17 | | 0.13 | 0.14 |
| | ELEVATION rad/sec | WAS | 0.45 | 0.57 | 0.53 | | 0.48 | 0.46 | | 0.35 | 0.34 |
| MAXIMUM ACCELERATION | AZIMUTH rad/sec$^2$ | MISSED | 0.72 | 0.47 | 0.60 | | 0.54 | 0.49 | | 0.47 | 0.48 |
| | ELEVATION rad/sec$^2$ | | 0.99 | 0.80 | 1.00 | | 0.79 | 0.74 | | 0.56 | 0.57 |
| TRACK TIME | SECONDS | | 2.00 | 2.05 | 2.17 | | 1.85 | 1.80 | | 1.60 | 1.80 |




ROCKET TRACKING

FIGURE 14

| | |
|---|---|
| $T_o$ | Time at launch |
| $T_o + \Delta t$ | Rocket Tracking Time |
| $P_1$ | Neutral Mirror Position |
| $P_2$ | Mirror position at time $T_o$ |
| $P_3$ | Mirror position at time $T_o + \Delta T$ |
| $N_2$ | Normal to mirror at $P_2$ position |
| $N_3$ | Normal to mirror at $P_3$ position |
| $\alpha$ | Reference Angle |
| $\beta$ | Mirror angle |
| $\gamma$ | Tracking angle |
| $D$ | Distance from LRTS to Launcher |
| $D + \Delta D$ | Distance from LRTS to Target |
| $L$ | Distance from Launcher to Target |

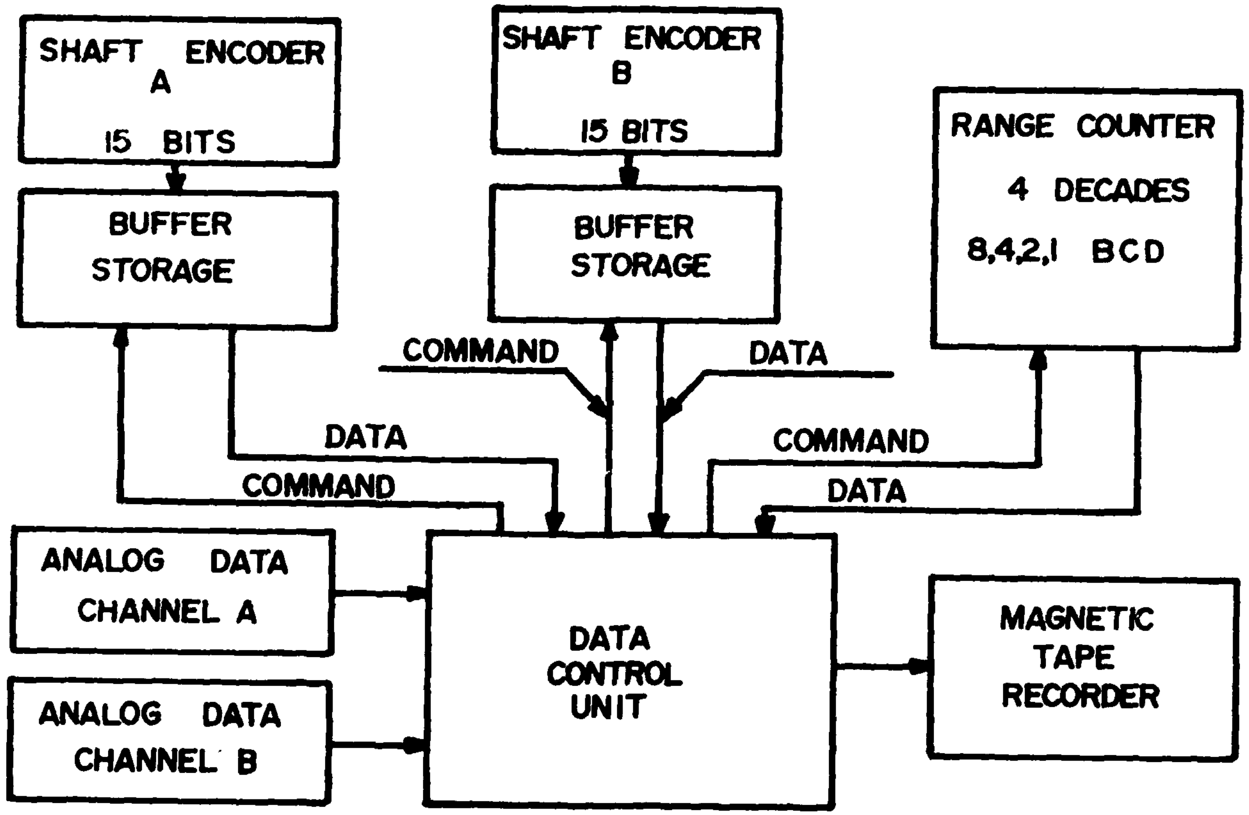
Maximum velocity and acceleration data are presented for both axes of the two-axis tracking mount. These data were calculated from the mirror angle data as a function of time. The two-axis tracking mount is limited dynamically by the servo motors to 2 radians per second in elevation velocity, 3 radians per second in azimuth velocity, 4 radians per second per second in elevation acceleration, and 5 radians per second per second in azimuth acceleration. From the data we see that at a distance of 2380 feet the mount was well within these limits. The tracking time indicates the length of time the rocket was actually tracked before it was lost.

Documentary films of these flights have been taken using motion picture cameras at two locations in the system. Narrow angle pictures at 200 frames per second (fps) showing the rocket being tracked were taken through the system optics at the point where the ranging photomultiplier would normally be located. A slower speed camera (24 fps) was used to obtain wide angle coverage showing the rocket, launcher, and a portion of the surrounding area. These pictures were taken from a fixed mirror which looked directly into the tracking mirror.

The means by which these results were obtained are obviously not as sophisticated and accurate as one would like. A precision digital data system has been designed and will be purchased and installed when funds become available.

## DATA SYSTEM

In order to determine the target position in space five parameters are necessary. They are: azimuth, elevation, range, azimuth error and elevation error. The proposed data system is shown in Figure 15. Shaft encoders will be installed on both axes of rotation of the two-axis tracking mount. These encoders will generate azimuth and elevation angular coordinates which will be used to locate the position of the target in space. Velocity and acceleration data can be calculated from the change of these coordinates and target distance as a function of time. Range information will come from the range counter in terms of feet at a maximum repetition rate of 3,000 per second. The error signals which indicate how far the target is from the center of the photomultiplier tube, will be generated by the photomultiplier electronics. These five signals will be processed by the digital control unit and recorded on IBM compatible incremental magnetic tape at a rate of up to 50 samples per second. If necessary the sampling rate can be increased by using a continuous run magnetic tape. When installation of the data system is completed, obtaining consistently accurate, reliable data will be a routine matter.




PROPOSED DATA SYSTEM

FIGURE 15

## CONCLUSION, RECOMMENDATIONS & FUTURE PLANS

The feasibility study, initial design and development and evaluation stages have been completed. The system evaluation includes tracking model rockets, which were scaled to simulate range conditions, and production 2.75- and 5-inch rockets fired under NWL Main Range firing conditions. The data presented were obtained without the aid of the ranging section and the PMT RRD. These data prove the capability of the NWL LRT to track rockets from launch through burn-out to a distance of 4320 ft - the initial objective. Since obtaining these data, both the ranging and the PMT RRD have been installed. Further evaluation tests utilizing updated electronics, optics and the PMT RRD have not yet been conducted, however, we anticipate the LRT will now track rockets to a much greater range, possibly to impact.

The system has been designed with as much flexibility as possible and future development will depend, at least in part, on potential user applications.

Immediate future plans call for:

1. Further 2.75- and 5-inch rocket tests from various locations.
2. Physical relocation of various components within the system to conserve space and improve accessibility of components.
3. Updating optics and electronics.
4. Developing a suitable retroreflective paint.
5. Installing a data retrieval system.
6. Installing a faster tracking mount, if necessary, for projectile tracking.
7. Projectile tracking evaluation tests.

## REFERENCES

1. C. S. Mangleburg, *Tracking of 2.75-Inch Rockets with a Laser Ranger/Tracker System,* NWL Technical Report 2414, April 1970

2. R. A. Frazer, *Presentation - Laser Ranger Tracker,* Unpublished Report.

3. L. R. Olson, *Laser Ranger/Tracker Accuracy Project,* Unpublished Report, December 1968.

# APPENDIX A

# SAFETY ANALYSIS

## SAFETY ANALYSIS

The Naval Weapons Laboratory is well aware of the importance of safety and considers it a primary feature incorporated into every experimental laser program from its very beginning. Laboratory-wide laser safety regulations have been established in addition to the special case procedures used in connection with the Laser Ranger/Tracker.

Since the laser beam associated with the LRT is directed to a distant target through open space, a high standard of safety must be maintained. Prior to assigning an employee to work on the LRT he is sent to the Safety Office where arrangements are made for an eye examination to determine the condition of his retinas. This is important in later determining whether a person has received retinal scarring as a result of exposure to laser radiation. Follow up examinations are performed annually, or sooner if there is reason to suspect eye damage.

All personnel, those operating the system as well as those preparing the target, are fully informed of the potential hazards associated with the equipment and the laser beam. Eye protection goggles designed for Argon wavelengths are provided and worn by each employee when working in the vicinity of the operation laser, or the target area where the beam is being directed. Signs and warning lights are posted conspicuously at the entrance to the van cautioning against entering while equipment is in operation. The LRT main control panel has a switch which opens and closes a cavity shutter assembly which allows the beam to be stopped with no reflection other that directly back along the original beam. This safety feature allows the beam to be stopped very quickly in case of an emergency.

All model rocket testing has been conducted at a site overlooking a portion of the NWL airfield. This airfield is seldom used and in the event a plane is coming in for a landing there is ample time to hear and locate it before it gets into a position where its personnel might be endangered by the laser beam. At the end of the test site, approximately 5,000 feet from the van, is a natural wooded area which stops the beam and eliminates any personnel hazard that might exist. If the LRT breaks track and the mirror "flies off" there are overriding switches which automatically actuate the laser beam shutter until the mirror returns to a safe position.

The 2.75- and 5-inch rocket field evaluation tests are conducted in the Main Range area. When testing is conducted in this area, the roads are sealed off by barricades eliminating traffic in the area. In addition, the beam crosses the road at a level higher than the normal car or truck. After crossing the road, the beam passes in front of the guns at the main battery where no personnel are allowed at any time during testing. On the opposite side of main battery are the launchers used for our tests. The distance between the LRT van and the launch site is approximately 2380 feet. The power density at the launch site is slightly above recommended safety levels. To preclude any accidents, extreme caution and very rigid procedures are adhered to.

When loading the rockets into the launcher the beam is shut off. After loading procedures are completed and all personnel are safely under shelter the firing officer in charge contacts the LRT van by radio and gives approval to proceed with locking the beam onto the target. Once lock-on is completed the firing officer is informed and only on his approval is the rocket fired and tracking completed. Here again the beam is prevented from entering a populated area while near ground level by a natural tree backstop.

Since the rockets are fired down the Potomac River care must be taken to insure the safety of the people crossing the Potomac River Bridge as well as those people living on the opposite shore line. Once the beam clears the tree line it is elevated enough to eliminate any hazard to the shore line and road areas. A search surveillance radar is used to monitor the sky continuously to prevent any airplane from flying into a dangerous area. If a plane is spotted by radar the radar operator contacts the LRT van by radio and the laser is immediately shut down.

All range tests are coordinated through the main range scheduling office allowing everyone concerned with the range to be familiar with the tests being conducted.

# APPENDIX B

# RETROREFLECTIVE MATERIALS

## RETROREFLECTIVE MATERIALS

The NWL Laser Ranger/Tracker at the present time requires a co-operative target. This means the target must be coated with some material to help reflect the laser light to the LRT. Several retroreflective materials have been evaluated. The material chosen for preliminary rocket tracking tests,Scotchlite Brand High Reflective Sheeting #7610, is a flexible plastic material covered with an even distribution of small reflective glass beads.

Figure 1 is a cross-sectional schematic of the sheeting. This proprietary material is composed of a single layer of closely packed glass beads. Each bead is bonded in at its equator to the plastic surface and acts as an individual retroreflector. Figure 1 shows a ray tracing on one of the individual beads. Comparing the reflecting ability of the sheeting to that of white paper, the sheeting is about 1000 times better, according to the manufacturer.

Preliminary evaluation tests have also been conducted on a retroreflective paint called Codit. Figure 2 illustrates small reflective beads applied to a surface in the form of a paint. Spraying or brushing this paint on a surface will not insure an even distribution of beads nor will each reflective bead be perfectly aligned as with the sheeting. At best one hopes for a random distribution of beads that will yield a fairly decent retroreflector. Figure 3 illustrates how the random bead orientation affects the retroreflective qualities. As can be seen at positions 1, 2 and 6 the laser light is prevented from entering the bead by the reflective coating. At position 4 the laser light enters the bead but there is no reflection due to lack of reflective coating. Position 7 normally would have a reflection but the coating prevents the reflected light from leaving the bead. Beads 3 and 5 are the only ones that give a perfect reflection.

Since the materials mentioned are proprietary, further inquiries concerning them should be directed to the manufacturer.

Further work with retroreflective paints is planned.

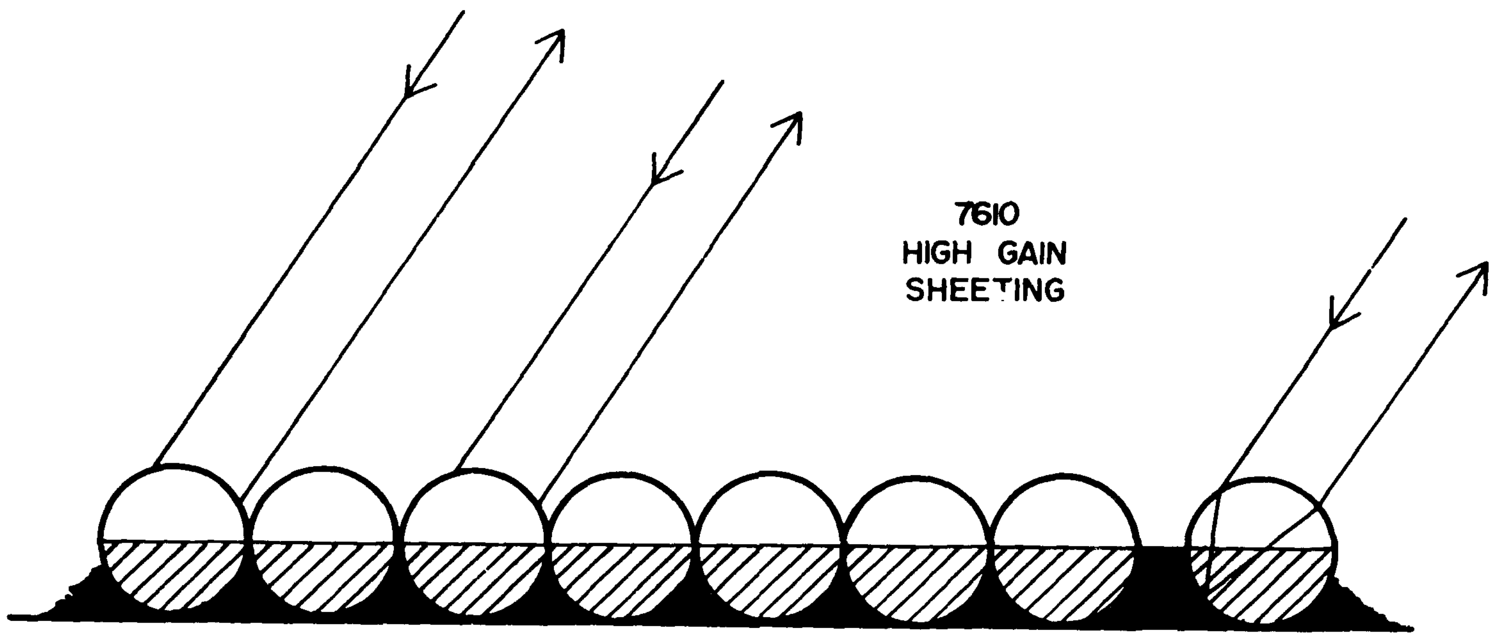
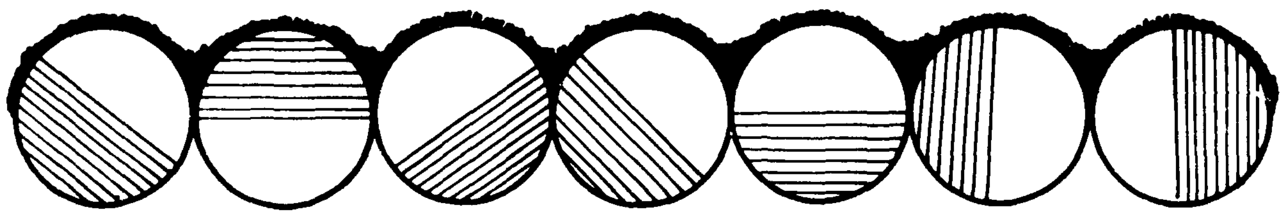
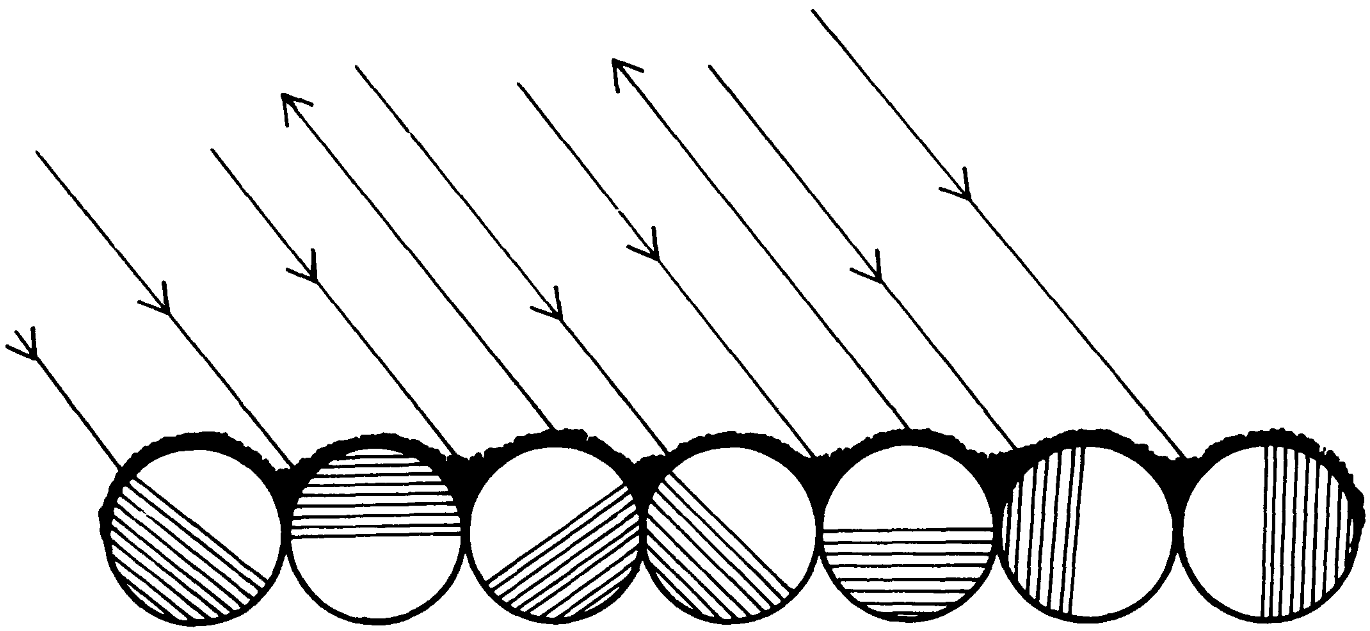



FIGURE 1



CODIT PAINT

FIGURE 2



CODIT PAINT WITH RAY TRACING

FIGURE 3

UNCLASSIFIED
Security Classification

## DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Naval Weapons Laboratory
Dahlgren, Virginia 22448

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

THE NAVAL WEAPONS LABORATORY LASER RANGER/TRACKER SYSTEM

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

N. Norbert Harold

6. REPORT DATE
November 1970

7a. TOTAL NO. OF PAGES

7b. NO. OF REFS

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
TR-2469

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

A working breadboard model of a laser-based missile tracking and ranging system has been designed and developed by the Naval Weapons Laboratory, Dahlgren, Virginia. The system has been evaluated under actual range conditions where it has demonstrated its capabilities in tracking 2.75- and 5-inch rockets over the initial portion of their flights. Video tapes and color movies of these flights are available for inspection.

The system is a self-contained mobile unit containing several subsystems. Each subsystem is an independent unit in that it can be modified to meet specific requirements without affecting other subsystems. Sufficient flexibility is inherent in the system to render it useful as a research tool or as a standard range instrumentation item.

The system is now at the stage where further development will depend on potential user requirements. It is, therefore, requested that potential users submit their requirements to the Naval Weapons Laboratory to aid in determining future needs for the system.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED
Security Classification

# U S NAVAL WEAPONS LABORATORY
# SCIENTIFIC, TECHNICAL and ADMINISTRATIVE PUBLICATIONS

**TECHNICAL REPORTS:** Scientific and technical information on the work of the Laboratory for general distribution.

**TECHNICAL NOTES:** Preliminary or partial scientific and technical information, or information of limited interest, for distribution within the Laboratory.

**CONTRACTOR REPORTS:** Information generated in connection with Laboratory contracts and released under NWL auspices.

**ADMINISTRATIVE REPORTS:** Administrative information on the work, plans and proposals of the Laboratory.

**ADMINISTRATIVE NOTES:** Preliminary or partial administrative information, or information of limited interest, for distribution within the Laboratory.

Details on the availability of these publications may be obtained from:

TECHNICAL LIBRARY
U S NAVAL WEAPONS LABORATORY
DAHLGREN, VIRGINIA