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NRL REPORT 3660

A COMPARATIVE STUDY OF THE XRAT AND XRAM GUIDANCE SYSTEMS BEING DEVELOPED FOR THE ANGLED·ARROW PROJECTILE

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A COMPARATIVE STUDY OF THE XRAT AND XRAM GUIDANCE SYSTEMS BEING DEVELOPED FOR THE ANGLED·ARROW PROJECTILE

Allen H. Schooley

May 23, 1950

Approved by:

Dr. R. M. Page, Superintendent, Radio Division III

DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH

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A COMPARATIVE STUDY OF THE XRAT AND XRAM GUIDANCE SYSTEMS BEING DEVELOPED FOR THE ANGLED-ARROW PROJECTILE

INTRODUCTION

The present Angled-Arrow Projectile program* consists of research on and design of a gun-launched, non-self-propelled, fin-stabilized, antiaircraft, guided-arrow shell. The missile has a cylindrical body, an ogive nose, and a fixed tail-fin section. The mid-section of the missile contains a transverse one-shot reaction-steering rocket unit which may be fired by a command signal to cause the missile to alter its course in flight. The missile is fin-stabilized and is fired from a smooth-bore gun by means of a sabot. A spin rate of the order of 10 rps is induced aerodynamically in the missile. This induced spin rate assures that the direction of the steering-rocket thrust vector will continually revolve about the longitudinal axis of the missile during flight. The guidance system can then select the particular range and orientation required and transmit the correcting, rocket-firing command to secure target interception.

There are two systems of command guidance under investigation. One is known as the XRAT system (experimental radio angular transmitter) and the other as the XRAM system (experimental radar angular mirror). In the XRAT system, the asymmetric radiation pattern generated by a radio sonde in the missile is received by a polarized antenna aboard ship. During the course of the flight, the guidance system, including a computer, determines the optimum range and angular position for deflection steering. At the optimum point the reaction steering motor is initiated by a pulse transmitted to the missile. In the XRAM system, a polarized, canted mirror mounted on the after part of the missile causes the portion of the tracking radar beam returned to the ground receiver to vary in a characteristic manner during each revolution of the missile. The orientation of the reaction steering jet can thus be established aboard ship during flight. The missile contains a receiver to which is transmitted the command signal to fire the reaction steering jet at the proper time along the trajectory and at the proper orientation.

The present comparative study of the XRAT and XRAM guidance systems was requested by the Naval Ordnance Laboratory in Reference (1). Reference (2) is the Naval Research Laboratory acceptance of the Naval Ordnance Laboratory request.

GENERAL PRELIMINARY DISCUSSION

Since the selection of the 8-inch, 55-caliber gun for use as a Zeus launcher is considered sound, this report will be concerned with the application of XRAM and XRAT guidance to the 8-inch, 55-caliber gun only. The USS DES MOINES (Figure 1) is representative of a class of cruisers that are equipped with rapid-fire, dual-purpose, 8-inch guns. For antiaircraft fire, one or more of the Directors Mark 37 are used to control one or more of the three turrets of three 8-inch guns each. Two Computers Mark 1 are available with 8-inch ballistics for use in these fire-control systems. It should be noted that the standard 8-inch guns on other ships can also be converted for Zeus launching.

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*The Angled-Arrow Projectile was formerly called Zeus. This change in name took place after the preliminary draft of this report was completed. Hence, subsequent reference to Zeus will refer to the present Angled-Arrow Projectile.

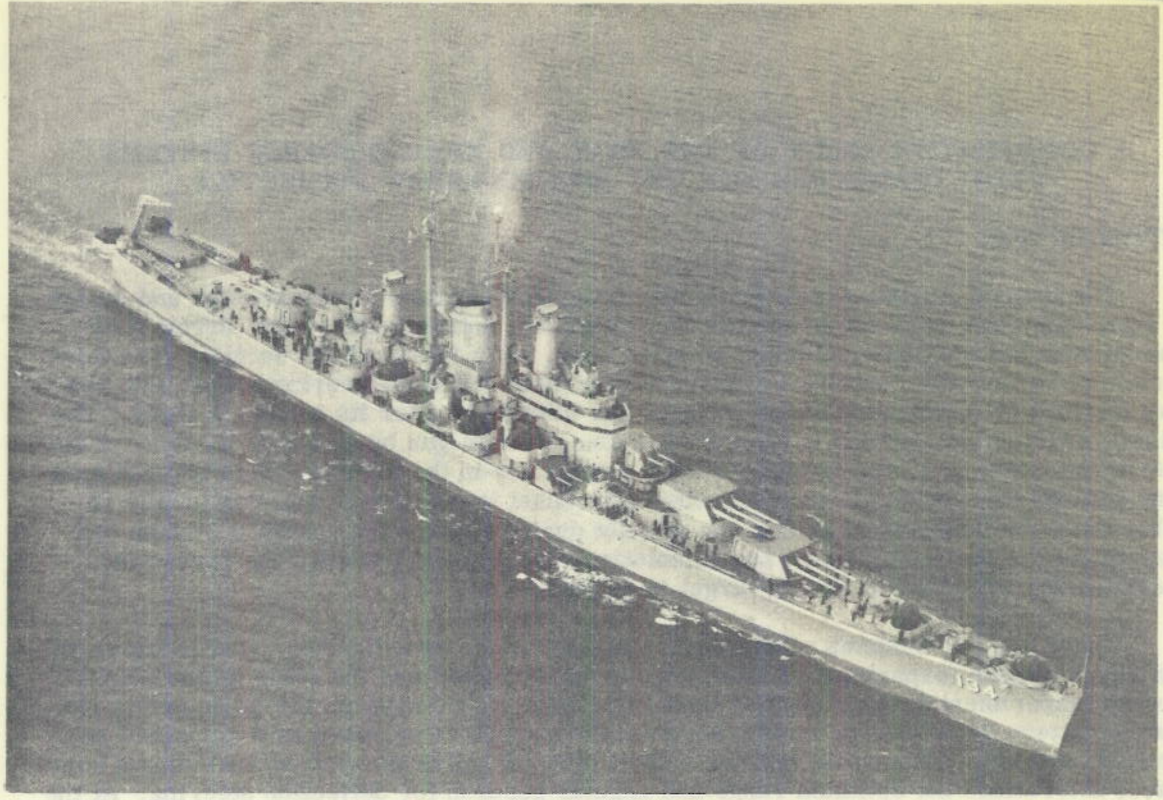


Figure 1 -- USS DES MOINES

Figure 2 compares the profile of the conventional 8-inch spin-stabilized Projectile Mark 24 with a representative 8-inch Zeus fin-stabilized projectile. The Zeus I-XG-4 embodiment that is shown is divided into three sections. Section (a) contains the warhead, section (b) contains the lateral thrust rocket motor for one-shot steering, and section (c) contains the proximity fuze and electronic equipment necessary for the command firing of the steering rocket.

For comparison, the trajectories of a Zeus-type projectile (initial velocity of 4,000 feet per second) for gun-elevation angles of 15°, 45°, and 60° are presented with similar trajectories for the conventional projectile (initial velocity of 2,200 feet per second) (Figure 3). In both cases initial velocities of about 500 feet per second greater may be used. The trajectories shown are the ones that were readily available at the time of writing. The present maximum gun elevation on cruisers of the DES MOINES class is about 40° It is evident from Figure 3 that, for gun-elevation angles less than 45°, the Zeus missile has trajectories for antiaircraft fire that should be useful for slowly maneuvering targets with horizontal range out to 15,000 to 20,000 yards and altitude up to about 40,000 feet. This maximum useful range is almost double that possible with the conventional Projectile Mark 24. At comparatively short ranges, however, the larger warhead of the conventional projectile must be considered in the comparison.

Figure 4 shows the approximate cumulative-kill probability as a function of slant range for four projectile configurations. In this case a maneuvering target is considered. Curve (a) is for the conventional spin-stabilized projectile; curve (b) is for the Zeus projectile assuming no rocket correction of the trajectory; curve (c) shows the cumulative-kill probability for the Zeus projectile with the steering rocket and electronic gear, except for the proximity fuze, replaced by additional warhead; and curve (d) is for the Zeus projectile with proper functioning of the one-shot guidance equipment. The assumptions used in determining the kill-probability curves are listed on Figure 4. Curves (b) and (d) are taken from Reference (3); and curves (a) and (c) were estimated on the basis of information in References (3), (4), (5), and (6). It is realized that there may be some error in the placement of the curves in Figure 4; however, it is believed that the relative order of the curves is correct under the given assumptions. It is interesting to note that in all cases Zeus is superior to the conventional projectile under the stated conditions.

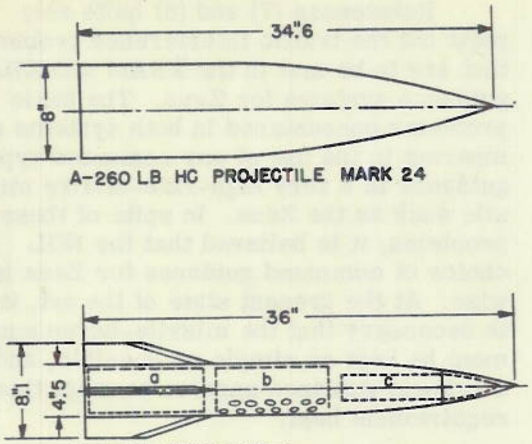


Figure 2 -- Profiles of 8-inch conventional and Zeus projectiles

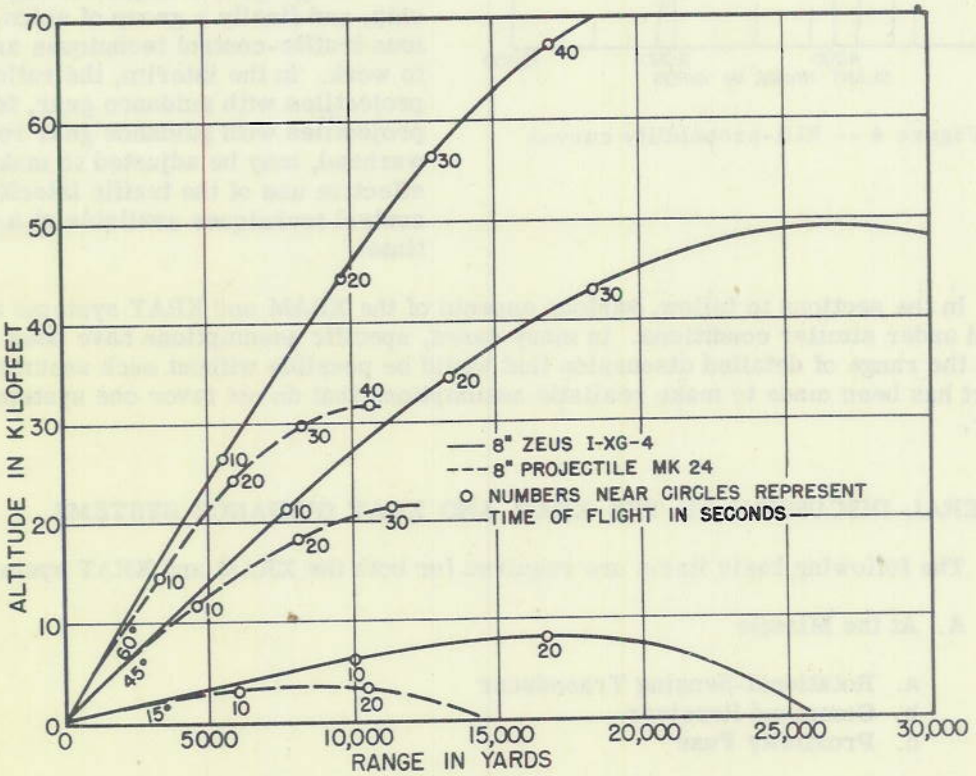


Figure 3 -- Trajectories of conventional and Zeus-type projectiles

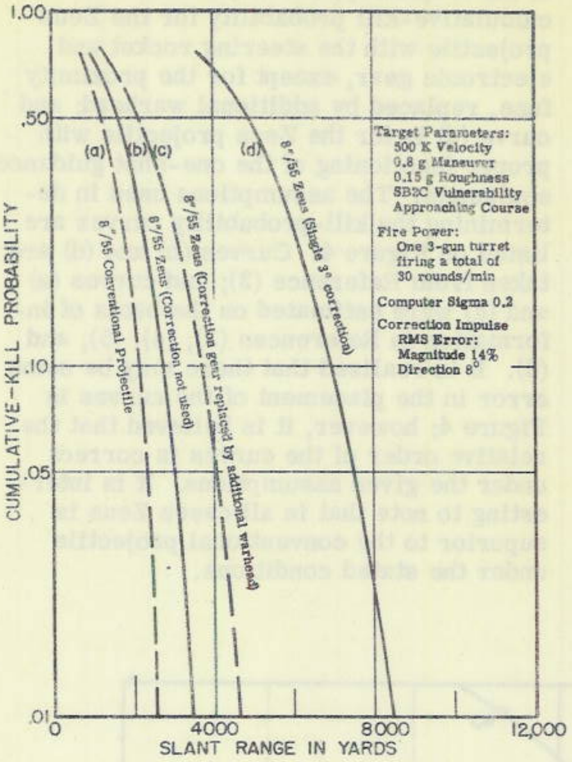


Figure 4 -- Kill-probability curves

References (7) and (8) quite ably point out the traffic interference problems that are to be met in the XRAM and XRAT guidance systems for Zeus. The basic problems encountered in both systems are inherent in the use of any command-type guidance in a very high-rate-of-fire missile such as the Zeus. In spite of these problems, it is believed that the NOL choice of command guidance for Zeus is wise. At the present state of the art, it is necessary that the missile-borne equipment be kept as simple as possible, and command guidance appears to meet this requirement best.

It is apparent from References (7) and (8) that there is no experimentally proven solution to all of the traffic-interference problems encountered when several ships are sending 90 rounds per minute toward a single aircraft. It is believed, however, that effective traffic-interference control can be demonstrated for a single gun, a single turret, a single ship, and finally a group of ships, as various traffic-control techniques are made to work. In the interim, the ratio of Zeus projectiles with guidance gear, to Zeus projectiles with guidance gear replaced by warhead, may be adjusted to make most effective use of the traffic interference-control techniques available at a given time.

In the sections to follow, various aspects of the XRAM and XRAT systems are compared under similar conditions. In many cases, specific assumptions have been made to limit the range of detailed discussion that would be possible without such assumptions. Effort has been made to make realistic assumptions that do not favor one system or the other.

GENERAL DISCUSSION OF THE XRAM AND XRAT GUIDANCE SYSTEMS

The following basic items are required for both the XRAM and XRAT systems:

A. At the Missile

a. Rotational-Sensing Transducer
b. Command Receiver
c. Proximity Fuze

B. At the Ship

a. Target-Tracking Radar
b. Gun-Order Computer
c. Rotational-Sensing Equipment
d. Command-Order Computer
e. Command-Order Transmitter

The following paragraphs will briefly describe the current visualization of the XRAM and XRAT equipment that will be associated with each of the items listed above. Comparison of the fundamentals of the two systems has been simplified by not considering traffic-interference problems. These problems are discussed separately in later paragraphs.

Items Required at the Missile for the XRAM System

The rotational-sensing transducer in the XRAM system consists of a flat reflector fitted into the after body of the Zeus projectile. The axis of the reflector, or mirror, may be placed at a fixed tilt of 10° to 20° with respect to the axis of the missile—it is possible that the angle will be varied as a function of flight time. The reflector will be approximately one wavelength in diameter for S-band radiation and about 3 wavelengths in diameter for X-band radiation. With either radiation it is planned to use slotted mirrors that give a polarized reflection.

It is proposed that the command receiver for the XRAM system will consist of an S- or X-band crystal detector followed by two stages of video amplification plus a decoder, perhaps of the phantastron type, and a correction-charge firing circuit. It has also been suggested that a superheterodyne receiver may be used by transmitting two command signals separated by, say, 20 Mc. The antenna for the receiver is to be built into the rear edge of the stabilizing fins.

The proximity fuze for the XRAM-controlled projectile is presently visualized as the conventional 5-tube VT fuze mounted in the nose. There exists the possibility of using a second command transmitted from the ground to the missile to fire the warhead at, say, the point where the range to the target and to the missile are equal.

Items Required at the Missile for the XRAT System

The rotational-sensing transducer in the XRAT system consists of a one-tube transmitter operating in the region of 160 Mc and exciting a modified VT-fuze antenna in the nose of the projectile. The antenna produces a pattern that is nonsymmetrical about the longitudinal axis of the projectile.

The command receiver for the XRAT system is to use the antenna and oscillator tube of the rotational-sensing transmitter as a part of the receiver system. The command signal transmitted from the ship will be about 20 kc removed from the frequency of the rotational-sensing oscillator, which will then act as a local oscillator and mixer to provide a 20-kc signal to a two-stage tuned amplifier. The output of the amplifier will activate the correction-charge firing circuit.

In the XRAT system, it is believed, but has not been demonstrated, that the rotational-sensing antenna and oscillator can perform a third function by acting as the proximity-fuze transceiver. The doppler frequency for the fuze application is a few hundred cycles and the detected signal will go through a three-stage tuned amplifier before going to the thyratron warhead igniter. There also exists the possibility of using a second command transmitted from the ground to the missile to fire the warhead at the point where the tracking radar indicates the range to the target and to the missile to be equal.

Summary of Equipment Required in the Missile

The equipment required in the missile for the two systems, including the proximity fuze, may be summarized as follows:

XRAM	XRAT
One radar reflector	One antenna
One VT-fuze antenna	About 8 tubes
One command receiver antenna	One oscillator-mixer
About ten tubes	One 3-stage tuned amplifier for VT-fuze
Five tubes for VT-fuze	One VT-fuze igniter
One 2-tube video amplifier for command receiver	One 2-stage tuned amplifier for command receiver
One 2-tube decoder	One correction-charge igniter
One correction-charge igniter	

Items Required at the Ship for the XRAM and XRAT Systems

At the ship, both guidance systems will require a high-performance target-tracking radar with the necessary acquisition equipment. Likewise, both systems will require a conventional gun-order computer.

The XRAM system will require a high-power, narrow-beamwidth, S- or X-band, rotational-sensing radar that is placed on the missile by a computer. After acquisition, the radar may be kept on the missile by the computer or may be designed to track the missile automatically. The rotational-sensing radar illuminates the rotational-sensing reflector on the projectile and receives, demodulates, and picks the peaks of the reflected signal. The XRAT rotational-sensing equipment consists of a relatively wide-beamwidth antenna and a 164-Mc receiver which demodulates and picks the peaks of the signal modulation.

The command-order computer requirements are somewhat the same for both systems. This computer compares the present predicted point of impact of the target and missile with the predicted point of impact at the time of firing. The computer then determines the optimum time for giving the correction firing order, which must be coincident with the optimum-rotational position as determined by the rotational-sensing equipment. The firing order is given to the command-order transmitter, which relays it to the command receiver, which in turn fires the correction charge.

The XRAM command-order transmitter will most likely be the radar transmitter used for illuminating the mirror on the missile. The firing command will be transmitted as a pulse-time modulation. The XRAT command-order transmitter will be a high-power transmitter operating in the region of 164 Mc with a relatively wide-beam, circularly polarized antenna.

Summary of Equipment Required at the Ship

Excluding the items that are essentially the same, we may briefly summarize the equipment required at the ship for the two systems as follows:

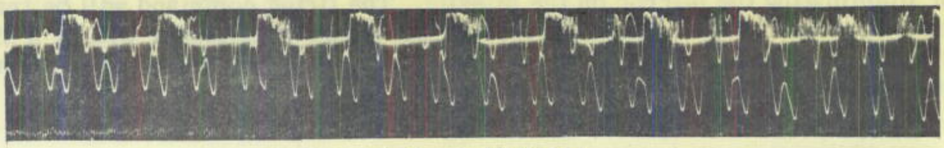
XRAM	XRAT
One radar antenna	Two 164-Mc antennas
One high-power, S- or X-band, radar transmitter	One high-power, 164-Mc transmitter
One radar receiver	One 164-Mc receiver

THE XRAM AND XRAT ROTATIONAL SENSING SIGNALS

Figure 5 shows samples of the video-output rotational-sensing receiver for Zeus-XRAM test flight No. 74. The video signal is the lowest record in each strip and is characterized by the 635-per-second repetition rate of the S-band SP-1M radar transmitter. The two middle traces are the output of two different detectors which had the video signal as input. The lower detector-output trace appears to be better than the upper detector-output trace and will be the one considered here. The topmost trace was created by a Sun-Sonde that was intended to give a signal each time an axial-slit lens in the projectile swept across the sun. Examination of the original record indicated that the Sun-Sonde gave usable index signals between about the 4- and 11-second points. These index marks are shown in the 5- and 10-second parts of the record shown in Figure 5. The periodic sharp rise in the Sun-Sonde trace are the index points.

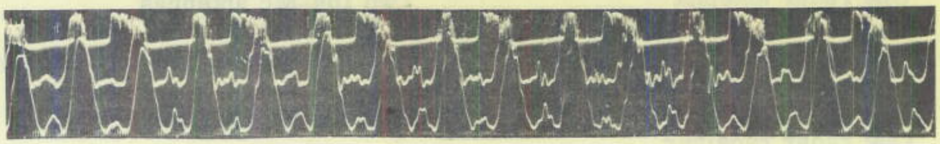
The record shown in Figure 5 was made on an experimental 8-inch Zeus projectile fired at 15° elevation at an initial velocity of 3,200 feet per second. The tilt of the polarized one-wavelength diameter, reflecting mirror was 13°.

At the 5- and 10-second portions of the XRAM modulation record (Figure 5), the primary and secondary peaks, created by the tilted polarized reflector that is rotating with the projectile, are clearly evident. Primary-to-secondary-peak modulation was found to be approximately 12 and 50 percent, respectively, for the 5- and 10-second points. At the 15-second point the primary peaks are highest in three out of the four of the primary peaks shown. Disregarding this one exception, the modulation is about 30 percent. The NOL-XRAM group's analysis of the original data indicates that the usable rotational-sensing signal stopped at about 16 seconds. No doubt this could have been extended considerably if a larger, mirror-tilt angle had been available or if the tilt angle had been increased with the time of flight. From trajectory data and the placement of the radar antenna, it is possible to determine the approximate angle between the missile axis, and the line of sight between the radar and the missile, for the three points mentioned. These data, together with additional points taken from the XRAM group's analysis, are plotted as the (x) points in Figure 6. Referring to Figure 5, it is evident that the apparent



1 second time of flight

2 sec



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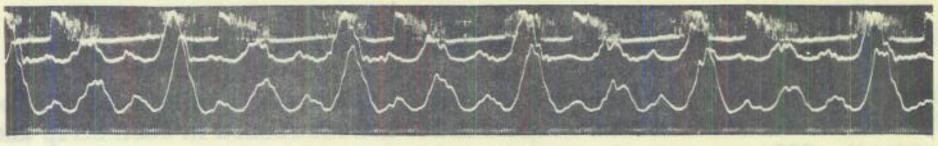

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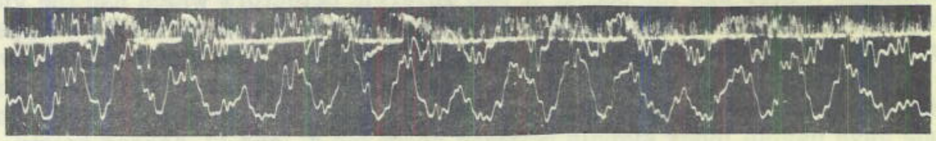

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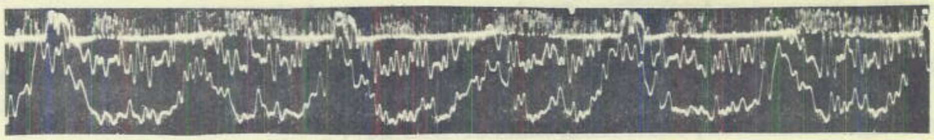

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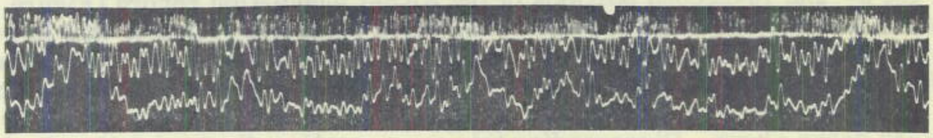

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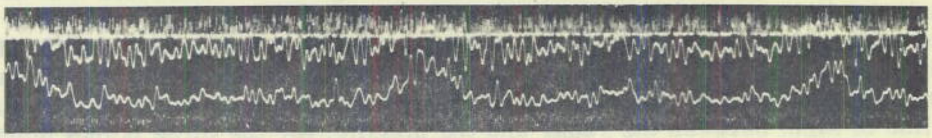

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Figure 5 -- XRAM rotational signals

percent modulation of the primary to secondary peaks at the 1- and 2-second points is not discernible due to equipment overloading caused by the strong signals at short range.

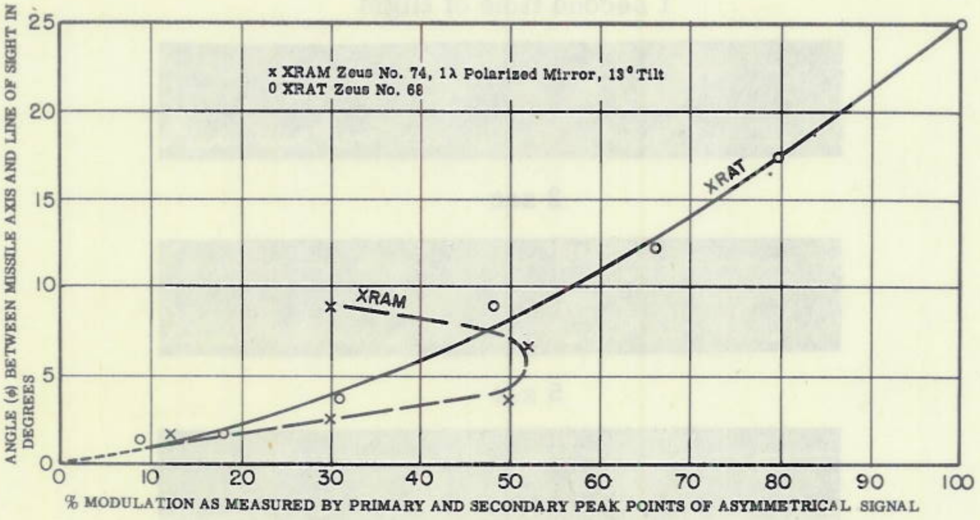
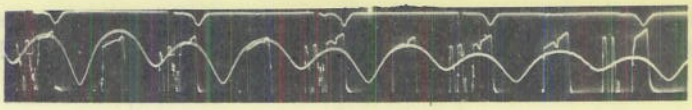


Figure 6 -- Asymmetrical signal modulation as a function of the angle between the line of sight and the missile axis

Also plotted on Figure 6 are XRAT points marked (o). These points were determined in the same way as the (x) points for XRAM. The basic XRAT data shown in Figure 7 was taken from the firing of Zeus No. 68. In Figure 7, the received rotational-signal envelope is the central trace that most closely approaches a sine wave in character. The other trace of interest here is the top one showing triangular, negative peaks that appear to be very nearly locked in phase with the rotational-signal envelopes. The negative peaks were created by a Sun-Sonde that gave a signal each time an axial-slit lens in the projectile swept across the sun. It is seen in Figure 7 that rotational information is available out to a time of flight of 30 seconds.

The solid curve of Figure 6 shows the approximate percent modulation as a function of the angle ϕ for the particular Zeus-XRAT firing. ϕ is defined as the angle between the missile axis and the line of sight. The dashed line shows a similar curve for the XRAM with 13° tilted mirror 1 λ in diameter. It is seen that the XRAM percent modulation increases faster than the XRAT percent modulation for values of ϕ less than about 6°. Beyond 6° or 7° the percent modulation for XRAM falls off rapidly while the XRAT modulation is still increasing out to at least 25°. A larger tilt angle on the XRAM mirror would tend to increase the ϕ ordinates all along the XRAM curve.

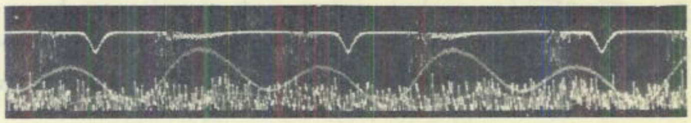
From Figure 3 it is possible to estimate the maximum useful time of flight for an antiaircraft Zeus to be about 30 seconds when fired at a gun-elevation angle of 45° and with an initial velocity of 4000 feet per second. The maximum usable time of flight for a 15° angle firing would be on the order of 20 seconds. Referring to Figure 8, it is evident that the angle ϕ for the 45° gun-elevation case is about 13° for 30 seconds time of flight, and for the 15° gun-elevation case is about 10° for a time of flight equal to 20 seconds. These points are beyond the bend in the percent-modulation curve for the XRAM system.



1 second time of flight

2 sec

5 sec



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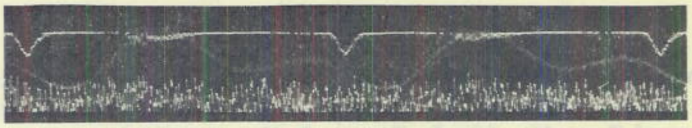

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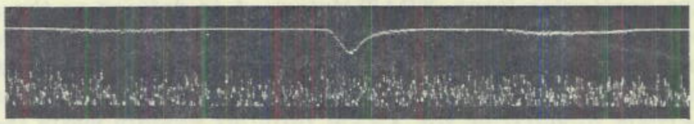

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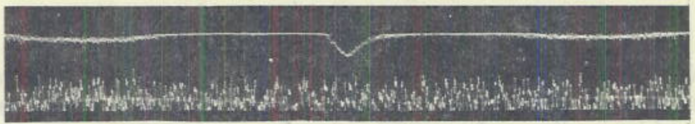

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Figure 7 -- XRAT rotational signals

However, it appears that this can be minimized by use of a larger, mirror-tilt angle as is planned. Choosing a fixed mirror-tilt angle will become more difficult if a 3-λ diameter mirror is used in conjunction with an X-band radar.

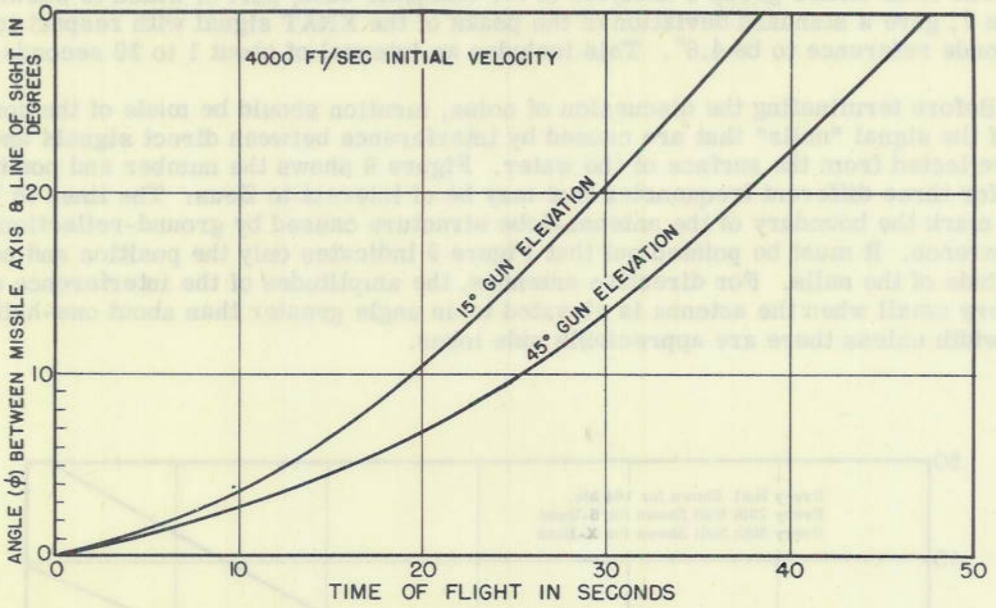

Figure 8 -- Angle between the line of sight and the missile axis as a function of time of flight

In either the XRAM or XRAT systems it is necessary to select the primary peaks of the signal modulation and then use this as a reference in selecting the proper rotational position for igniting the missile-correcting charge. To perform this function adequately, the rotational-position signal should have a minimum of noise in the frequency spectrum near the rotational frequency. It should also have a percent of primary-to-secondary-peak modulation sufficient to actuate realizable electronic circuits. It is believed that 5 percent modulation may be an acceptable minimum. Extrapolating from Figure 6 it appears that the 5 percent modulation minimum may be attained for values of φ greater than about 1/2°.

NRL made an analysis of the complete XRAM data, part of which is shown in Figure 5, between 4 and 11 seconds to determine the standard deviation of the primary peaks with respect to the Sun-Sonde reference. It was only in this region that the Sun-Sonde was working. The standard deviation was found to be 5.8°.

The NOL-XRAM group has evolved a technique for improving the standard-deviation measurements by a factor of about two, which is interesting because it shows promise of giving improved "peak-picker" circuit performance. The XRAM group measured the mean position of the primary peaks with respect to the Sun-Sonde reference, at a point about 30 percent down from the peaks. By this method the standard deviation for the same interval was about 2.8°. This type of analysis has not been made for XRAT records but it may be useful in improving their accuracy. To adapt such a method for actual use it would be necessary to use the conventional peak picker solely to determine the primary peaks of the XRAM or XRAT signals. These signals would then be used to activate a circuit that would measure the mean position of the major peaks at a point that may be considerably below the minor peaks.

The NOL-XRAT group's analysis of the complete data, part of which is shown in Figure 7, gave a standard deviation of the peaks of the XRAT signal with respect to the Sun-Sonde reference to be 4.8°. This includes an interval of about 1 to 28 seconds.

Before terminating the discussion of noise, mention should be made of the contribution of the signal "nulls" that are caused by interference between direct signals and signals reflected from the surface of the water. Figure 9 shows the number and position of nulls for three different frequencies that may be of interest to Zeus. The lines in Figure 9 mark the boundary of the antenna-lobe structure caused by ground-reflection interference. It must be pointed out that Figure 9 indicates only the position and not the amplitude of the nulls. For directive antennas, the amplitudes of the interference effects are very small when the antenna is elevated to an angle greater than about one-half to one beamwidth unless there are appreciable side lobes.

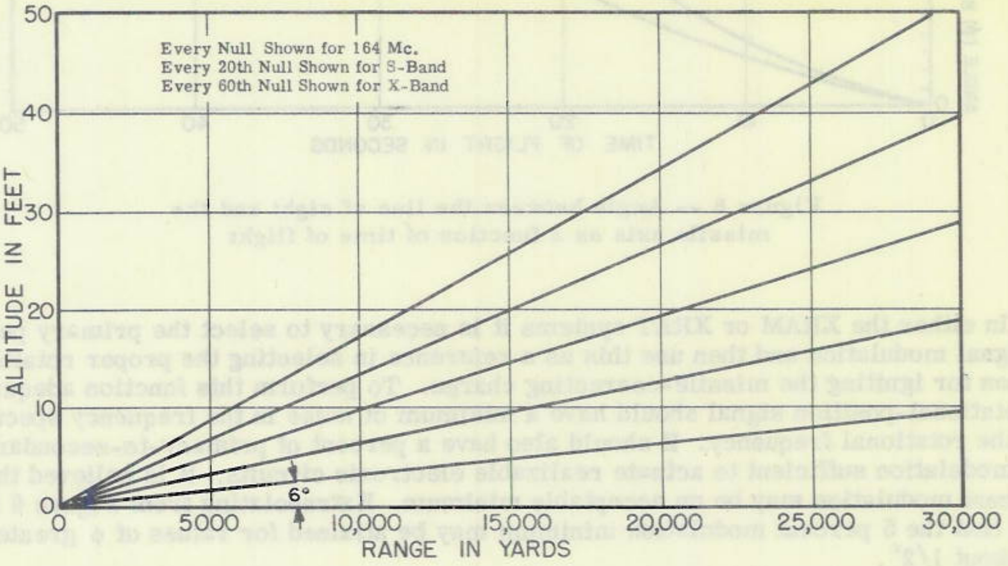

Figure 9 -- Positions of nulls due to surface reflection

For purposes of discussion, we will assume that a Zeus is fired at 6° elevation and has a 10-second time of flight before it hits the water. If all nulls have appreciable amplitude, there will be an average modulation of 6, 2, and 0.1 cycles per second for X-band, S-band, and 164 Mc, respectively. It is evident that in the last case the modulation due to surface reflection nulls is greatly removed from the missile rotational frequency of 30 to 5 revolutions per second and no appreciable errors in angular position measurement should be experienced from this source. In the case of S- and X-band, the null modulation can lead to errors if antenna-elevation angles are used that are part of a beamwidth.

A final comparison of Figures 5 and 7 indicates that noise near the rotational frequency appears to be more noticeable in XRAM than in XRAT. Below are listed two reasons explaining this observation.

a. The effective "carrier frequency" of the XRAM modulation signal is the repetition rate of the radar whereas the XRAT modulation carrier frequency is the r-f carrier frequency. For Figure 5 the radar repetition rate was 635. This rate can be increased for XRAM use.

b. The XRAM signal shows the characteristic erratic pulse-to-pulse amplitude noise that is characteristic of practically all radar reflected signals.

The discussion of the XRAM and XRAT rotational sensing signals may be summarized as follows:

a. A 27-second interval of XRAT Zeus Test No. 68 gave a standard deviation of the major peaks with respect to a Sun-Sonde reference of about 4.8°. A 7-second part of XRAM Zeus Test No. 74 gave a standard deviation of the major peaks with respect to a Sun-Sonde reference of approximately 5.8°. (The XRAM figure is reduced to 2.8° by the NOL-XRAM group's method for determining the mean of the major peaks as described in the text. This method may also be applicable to XRAT.)

b. The evidence indicates that there are several factors that tend to make the XRAM rotational signal more "noisy" in the desired pass band than the XRAT rotational signal.

THE SHIPBOARD ANTENNAS

The largest lead angles are associated with long-range pass courses. Figure 10 shows a plan plot of a 500-knot target circling the USS DES MOINES at 18,000 yards in a 0.4g turn. The time of flight for a Zeus with initial velocity of 4,000 feet per second to reach an aircraft flying under 10,000 feet altitude, would be about 22 seconds. Suppose the target is moving clockwise and its successive positions at 2-second intervals are represented by the dots along its course. At zero time, the ship has acquired and is tracking the target and a computer solution has been reached. The gun-lead angle would be about 19° in train if perfect curved-course prediction were used. (The super-elevation would be about 6.5°.) Under this circumstance no Zeus correction would be required if all other systematic and random errors were zero. If straight-line prediction were used, the lead angle would be slightly over 20° and the Zeus correction would have to be about 4° if applied at the time when the missile is 4,000 yards from the correct point of impact. The latter construction is not shown on Figure 10.

At zero time, the tracking radar is looking along the line of sight (long dashes) (Figure 10), and the missile is fired along the solid line. Time in seconds is marked along the path of both the target and the missile. If it is desirable to make a Zeus correction at the time the missile is 4,000 yards from the point of impact, the radar will be trained along the line with short dashes and the gun will be trained along the dot-dashed line. The angles that these lines make with a line to the point of impact are about 6° and 13°, respectively.

It is necessary that either the XRAM or XRAT rotational-sensing antenna beam and the command-transmitter beam are wide enough or placed accurately enough to be on the

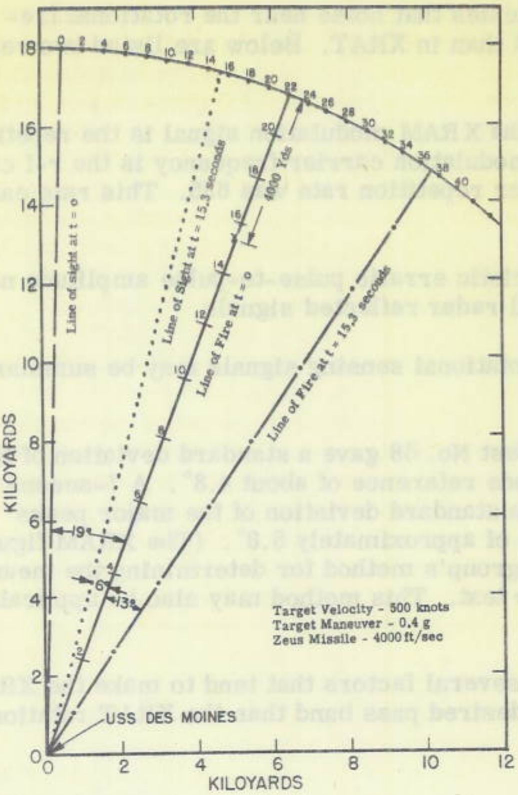

Figure 10 -- Diagram showing line of fire and line of sight relationships for a particular situation

missile for as long as possible before the time of the firing. The proposed XRAM S-band antenna, combining both of these functions, has about a 3-degree beamwidth; the XRAM X-band antenna being considered has a beamwidth of about 2°. Figure 10 indicates that a servo drive that is driven by the computer will have to be made available to put the antenna on the missile to within a part of a beamwidth. It is important that the amplitude and frequency of the jitter of this computer and servo system be such that it does not contribute appreciable amplitude noise to the missile, rotational-angle sensing function of the radar. Reference (10) gives roll, pitch, and yaw information for the Cruiser USS MACON for three sets of conditions. The XRAM antenna will have to be stabilized in order to stay on the missile and to give reasonably accurate rotational position.

It is theoretically desirable that the radar be lower than the gun in order to have appreciable rotational-sensing modulation of proper polarity at short ranges and at low gun-elevation angles. Practically, it may not be necessary to attempt either type of Zeus control at ranges less than about 4,000 yards, which amounts to about three seconds time of flight, because within this range the kill probability from unguided fire is fairly acceptable. As can be very roughly estimated from Figure 8, about 3 seconds of flight will be required to give a value of ϕ of over $1/2^\circ$. As has been pointed out previously, $\phi = 1/2^\circ$ will probably produce an acceptable minimum of 5 percent modulation of the asymmetrical signal if the antenna is mounted at the gun. It can be shown that moving the antenna 70 feet above the gun will have quite a small effect in diminishing ϕ at 3 seconds time of flight. Seventy feet is the vertical distance between the top of the forward 8-inch turret and the forward Gun Director Mark 37 shown in Figure 1. It is believed that a 70-foot difference in height represents the maximum that would be used.

In examining Figure 1, it is difficult to visualize how XRAM or XRAT antenna mounts can be placed aboard ship to cover the angles commanded by the guns without mounting them in such places as upon the gun turrets, in front of the gun turrets, or between the forward main battery director and the forward Director Mark 37. The gun-turret locations would require a particularly rugged XRAM antenna mount and stable servo system to withstand the blast of firing several rounds per minute without introducing unwanted modulation in the rotational-sensing information.

It will be assumed that the XRAT guidance system will require two shipboard antennas, one plane-polarized yagi antenna for receiving rotational-angle information, and one circular-polarized helical antenna for transmitting the command-guidance pulse. If the XRAT antennas are mounted on the top of 8-inch gun turrets, the antenna will probably require a linkage that will elevate them with the guns. The yagi rotational-sensing antenna will require roll stabilization. The beamwidth of the yagi rotational-sensing antenna will be about 50°. The circularly polarized command antenna will have a beamwidth of about 30°. It is these broad beamwidths that make positioning of the antennas much less critical than is the case for XRAM. The roll-stabilization problem, however, is essentially the same in both systems.

In summary it may be said that the single, narrow-beam, XRAM antenna presents a slightly more difficult shipboard-servo problem than that of the two relatively broad-beam XRAT antennas.

TRAFFIC INTERFERENCE PROBLEMS

The purpose of a traffic-control system is to make possible the separate recognition of each of several missiles by the guidance station, the separate determination of rotational position, and the transmission of separate deflection commands. This section of the report considers some aspects of the traffic problem. Figure 11, which has been prepared to help visualize the problem, is similar to Figure 10 in that a 500-knot target is flying a circular course of 18,000 yards radius around the DES MOINES. At time 0, the ship has acquired and is tracking the target aircraft as represented by the dashed line. Also at $t = 0$, firing is started at a rate of 30 rounds per minute or one shot every 2 seconds as would be the case for one 3-gun turret. The first gun fires the first missile at $t = 0$ along the plan plot of the trajectory represented by the first solid line which shows the approximate position of the missile at intervals of 2 seconds. The second gun fires its first missile along the plan plot of the trajectory represented by the first dotted line at time $t = 2$. At time $t = 4$, the third gun shoots along the plan plot of the trajectory represented by the dot-dashed line. At $t = 6$ seconds, the first gun will shoot along the plan plot of the trajectory represented by the second solid line and the process will be repeated.

In order to visualize the traffic of projectiles from all three turrets of a single ship, it is necessary to imagine three times as many lines with three times as many projectiles. The lines and projectiles will not necessarily be evenly spaced as will probably be the case for a single turret.

Now let it be assumed that the DES MOINES is firing XRAM-controlled Zeus missiles and that there is one radar antenna, receiver, transmitter, and operating frequency for each of the three turrets. Thus, each turret may fire independently of the others without the possibility of confusion. In order to simplify this discussion, let it be assumed that the Zeus-control point is always 4 seconds before the idealized point of impact at the target; that 1-1/2 seconds are required to generate the rotational-position information after the missile has been acquired in angle and range by the XRAM radar; and that the acquisition will require 1/2 second. The acquisition of successive missiles will have to be done by a computer. If automatic rather than computer-directed tracking is desired, it will probably be necessary to use a monopulse system because the missile-spin frequency covers the range usually used by sequential-lobing systems.

The following discussion will consider only one turret because all turrets have been assumed to be independent. Under the assumptions of the preceding paragraph, the first missile must be acquired by the XRAM rotational-sensing system before $t = 16\text{-}1/2$ seconds. Between $t = 16\text{-}1/2$ seconds and $t = 18$ seconds, the rotational-sensing signals will be interpreted in order to produce a reliable rotational reference to be used in timing of the firing of the correction charge at $t = 18$ seconds. Between $t = 18$ seconds and $t = 18\text{-}1/2$ seconds the acquisition computer must shift the XRAM radar antenna approximately 2° to

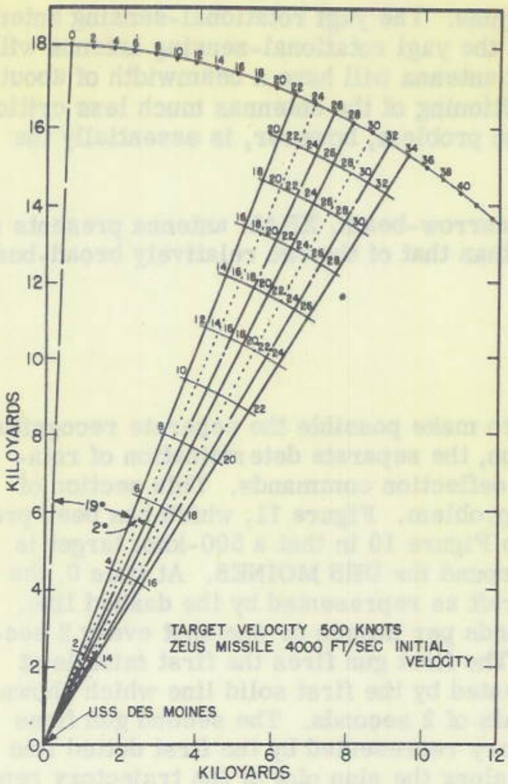

Figure 11 -- Diagram showing Zeus traffic relationships for a particular situation

the right and acquire the second missile in range. (It should be noted that for a similar target flying at a radius of 9,000 yards the antenna shift for acquiring successive missiles will be about 4°. On the other hand, a straight approach course will require no motion of the antenna for acquiring successive missiles.) Between t = 18-1/2 seconds and t = 20 seconds, reliable sensing information will be established for the second missile, which will have its correction point at t = 20 seconds. The XRAM radar is next shifted 2° to the third missile and the process is repeated at 2-second intervals as long as firing is continued. Only by using additional XRAM radars on the director will it be possible to accomplish acquisition, to determine the rotational position, and to transmit the command signal in less than two seconds time. It is evident that for a situation such as that shown in Figure 11 the acquisition of all but the first missile must be accomplished at greater than 14,000 yards range.

For approach courses and for long-range, low-velocity, pass courses, the successive missiles may travel within the beamwidth of the XRAM radar. In such cases the command-guidance signal for one missile may reach several missiles that are in flight at shorter range. In order to avoid this possibility, it will be necessary to send coded command signals to be decoded by the missiles, or the novel "phantastron" bracket-gating method described in Reference (9) must be used. The latter proposal suggests that each radar pulse as it is received by the successive missiles in the air be used to open a gate in each missile receiver. When this gate is open, the successive receivers are receptive to a firing-command pulse that may be transmitted at the proper time (between any successive radar pulses) in order to deliver the command signal at the missile closest to the target. Only the missile nearest the target will receive the command pulse because a time-of-flight computer in each missile will close the gate in each missile as a function of range. Thus the gates of the missiles farther away from the target than the first one will be closed before the command pulse for the first one is received.

It is believed that the proposal outlined in Reference (9) does not allow missiles not requiring correction to go to the target without being fired by the command to fire the succeeding missile. This apparent defect can be eliminated by adding another circuit to delay starting the gate in each missile as a function of time of flight from the reception of the radar pulses.

The proposal of Reference (9) requires the placement of a novel, fairly accurate, automatic bracket-arming system in each missile, thus eliminating the need for a "fuze-set" type.

The assumption that there is a separate XRAM radar-operating frequency for each turret will now be discussed. The XRAM system may use a crystal-video command receiver because S- and X-band local oscillators suitable for gun launching are not now available. On the basis of S- and X-band beacon experience, it is believed that practical crystal-video receivers will require a frequency separation of the order of 100 Mc for each turret. This separation will be necessary to prevent interference between command signals from the various turrets firing at the same target. Thus the maximum separation of frequency on a ship with three turrets would be about 200 Mc. This means that a "fuze-set" frequency adjustment will be required on a single type of ammunition on an XRAM-equipped ship. It has been suggested that a superheterodyne type of command receiver may be used by transmitting both the regular signal and a signal corresponding to the usual local oscillator. This type of receiver can be made less microphonic and more selective than the crystal-video type of receiver. Even so, it will be necessary to make "fuze-set" frequency adjustments so that a single type of ammunition may be used by all turrets on a ship. Pulse-time coding may be used instead of frequency discrimination to eliminate traffic interference between turrets. Here again it will be necessary to "fuze-set" the code so that the same ammunition can be used for all turrets.

When several ships are firing at the same target the narrow beamwidth and range gating of the XRAM radar help minimize rotational sensing and command interference between similar systems operating at the same frequency on two different ships. For the situation shown in Figure 11, and assuming a 2-degree beamwidth, the angular separation of two ships firing at a single target should be about 12° when measured at the target to insure very little interference. This means a minimum separation of a little less than 4,000 yards when both ships are at the same range from the target.

The discussion of XRAT traffic-control problems will also be made in terms of Figure 11. Again it will be assumed that the correction point will always be 4 seconds before the idealized point of impact. The beamwidth of the XRAT antennas for rotational-signal reception and command transmission are wide enough so that no auxiliary equipment, other than antennas mounted to move with the guns or move with the director line of sight, is required. Thus, acquisition of a missile consists solely of gating it in frequency by a receiver—the present realizable drift of the missile oscillator during a 15,000g acceleration is 0.3 Mc. It therefore appears probable that a practical adjacent-channel separation of 1/2 megacycle may be attained. It has also been experimentally verified that missile oscillators can be tuned through a 17 Mc range by means of a screwdriver adjustment. Therefore, a calibrated-trimmer control may ultimately lend itself to setting the frequency prior to firing similar to the setting of a fuze. It also appears possible that an arming device, which will be mentioned later, may be used to shift the frequency of the missile oscillator to a frequency assigned for proximity-fuze operation, thus eliminating interference between the proximity-fuze and the command-guidance phases of successive missiles.

Let it now be assumed that each turret is assigned a group of three frequencies, one for each gun or a total of 9 frequencies for a given ship. As indicated previously it will be possible to use the same basic ammunition with a "fuze setting" prior to firing to set the frequency for a particular gun. Under this assumption, speaking of a single ship and using available receivers, there will be no appreciable interference between successive projectiles from the same gun. Also, as far as radio interference is concerned, it would be possible to fire the various guns in salvos, at random, or successively.

A particular gun will be fired at intervals of 6 seconds, which allows 6 seconds time to acquire each missile in frequency, derive the rotational-angle information, and fire the correction rocket before it is necessary to concentrate on the next missile. Referring to

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Figure 11, the three solid lines represent the plan plot of the trajectories of three successive shots from a single gun. The first shot along the first solid line may be acquired in frequency, the rotational position information derived, and the correction command given at t = 18 seconds. In order for the second shot along the second solid line to keep from interfering with the first shot, it will be necessary for it to remain off the air until the 18-second point. This will require a delayed "arming", or delayed turning-on, of the missile oscillator until t = 18 seconds. It will be necessary to accomplish the delay before firing by means of a "fuze-setter" mechanism which uses a computer order. This same mechanism may be used to shift to the proximity-fuze frequency after the correction point is reached. At t = 18 seconds, the oscillator in the second projectile from the same gun (second solid line) is turned on and six seconds are available for acquisition in frequency and derivation of the rotational-position information. Command firing of the correction rocket would be at t = 24 seconds, after which time the third missile (third solid line) would be activated, and acquired, and the rotational information derived. The process is repeated as long as firing is continued. It is evident that, for the situation described, the acquisition of all but the first missile must be accomplished at a range greater than about 12,000 yards.

Speaking in terms of one ship, the above process will require a pulse-command transmitter and transmitter antenna for each turret. For the example given, each 160-Mc transmitter must be able to give commands of 300-microseconds duration at 2-second intervals and on one of three frequencies separated by 1/2 Mc from each other. It has been estimated that the pulse power of the transmitter must be between approximately 50 kw and 150 kw. Each turret will require one receiving antenna and three receivers (one for each gun).

The wide beamwidth used by XRAT does not permit appreciable interference reduction by this means when several ships are firing at the same target. It appears that frequency diversification will provide the most in interference reduction and also make jamming more difficult. If 1/2-Mc bands were used between 150 and 167 Mc, there would be 34 frequency channels available. This 17-Mc band, that has been covered by a screwdriver adjustment, would be sufficient to allow three ships to fire at a single target without interference and in addition have seven proximity-fuze channels. It is now quite certain that up to three ships may use identical ammunition. At the present state of the art, ammunition that is manufactured to operate on other frequency bands will be required if more than three ships are expected to be shooting at the same targets. It is believed to be very improbable that more than three 8-inch cruisers will be firing at the same target at the same time. A practical diversification of frequencies and their assignment will require consideration for probable tactical deployment of Zeus-XRAT-equipped ships.

The traffic interference summary for the XRAM and XRAT systems is as follows:

a. For the example assumed, and for the XRAM embodiment assumed, there will be 2 seconds available for acquisition of a missile in range and angle and for the derivation of the rotational-sensing signal. This compares with 6 seconds time available for acquisition in frequency and for derivation of the rotational-sensing signal for the XRAT embodiment assumed. The XRAM will be required to acquire successive missiles at about 2000 yards greater range than XRAT.

b. XRAM proposes a novel "bracket-gating" system built into the command receiver of each missile, thus eliminating "bracket-arming" before launching. XRAT proposes to use pre-launching "bracket-arming" of the command receiver.

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c. XRAM will probably permit identical ammunition to be "fuze-set" to the frequency assigned to each turret of a ship. XRAT will permit identical ammunition to be "fuze-set" to the frequencies assigned to each gun.

d. Inter-ship traffic interference is minimized by narrow beams in the XRAM system. XRAT depends upon a large number of narrow-frequency channels "fuze-set" at the guns to minimize this type of traffic interference.

JAMMING

Both XRAM and XRAT can be jammed but this possibility alone should not stop their development. Jamming is always a series of measures and countermeasures, and both systems offer countermeasure possibilities.

The relatively narrow beams used by XRAM make it relatively safe from jamming by sources not near the target. A jamming source at the target will have the advantage of a one-way path for jamming the rotational-sensing signals whereas XRAM requires a two-way path to derive this information.

The XRAT system is vulnerable to off-target jamming. The frequency diversification and narrow-frequency bandwidth requirements for XRAT are helpful factors in the jamming problem.

SUMMARY AND COMMENTS

a. It is believed that the NOL-Zeus research and development program was well conceived and is being ably executed. Strong support of the program is highly recommended.

b. It is believed that the XRAM system will require more equipment in the missile than the XRAT system when it is assumed that a proximity fuze will be necessary in both.

c. The best, present, experimental evidence shows that the XRAM rotational signals are less accurate than the XRAT signals when compared on a similar basis. There are several factors that tend to lead to the conclusion that XRAM rotational signals will ultimately be more noisy than XRAT rotational signals.

d. Under the conditions of an example given in the text, the XRAM radar will require that the acquisition computer place the radar on successive missiles at two-second intervals. Within each interval the rotational position at the command point must be determined and the firing command transmitted. The XRAT system does not require acquisition by the computer and has six seconds to do the other operations.

e. In XRAM, it is proposed to use a fairly accurate automatic bracket-gating system built into all missiles. In XRAT a less precise bracket-arming device will be "fuze-set" before firing.

f. "Fuze-set" tuning of XRAM ammunition will be required to place the command receiver on the frequency assigned to each turret. "Fuze-set" tuning of XRAT ammunition will be required to place the missile oscillator on the frequency assigned to each gun.

g. Inter-ship traffic interference is minimized by narrow beams in the XRAM system. XRAT depends upon a large number of narrow frequency channels to minimize this type of interference.

h. Both systems, like all radio or radar systems, can be jammed. In XRAM, jamming is minimized by the use of narrow beams. In XRAT, jamming is minimized by frequency diversification.

i. XRAM offers the possibility of getting a check on a given missile's position just before giving the correction command, thus improving the accuracy of fire. Let it be assumed that the missile-position data derived by radar can be made more accurate than that derived by a ballistic computer. To obtain and use this type of correction during the two-second interval that is also being used for several other operations (see (d) above) will certainly complicate an already tight situation.

j. It is believed that both XRAM and XRAT guidance can be made to work well enough to be of considerable advantage in the antiaircraft application of the 8-inch guns. More time and effort will be required to attain this goal using XRAM than XRAT.

k. Command-guidance systems, including both the XRAM and XRAT systems, become more difficult to use as the volume of fire towards a given target is increased. The Zeus traffic-interference problems appear to be soluble for the case of the 8-inch rapid-fire guns. Application to guns larger than 8-inch should be practical.

RECOMMENDATIONS

a. It is recommended that all possible support and engineering effort be concentrated upon the considerable task of developing the XRAT guidance system into an operational device to be used with 8-inch antiaircraft guns.

b. It is recommended that consideration be given to combining the Zeus guidance activities into one organizational unit.

* * *

REFERENCES

The following list is not a complete bibliography. In preparing this report the available published and unpublished material on the XRAM and XRAT guidance systems was studied. Due to the large amount of material, use of the complete bibliography proved to be impractical.

1. Letter from Director, NOL, to Director, NRL, dated 19 Dec. 1949
2. Letter from Director, NRL (1100-1/50/lp (72171)), to Director, NOL, dated 9 Jan. 1950
3. Lane, D. C. "A Comparison of Zeus and other Arrow Missiles with Conventional Antiaircraft Projectiles on the Basis of Kill Probabilities," NOLM 10605, 28 Dec. 1949 (Confidential)
4. Kaplan, E. L. "One-Shot Kill Probabilities for Guided Arrow-Shells and other Projectiles," NOLM 9559, 3 Feb. 1948 (Confidential)
5. O.E.G. Study #404 (Secret)
6. "Naval Gunfire Against Future Aircraft Targets," BTL report to BuOrd, 1 Feb. 1947 (Secret)
7. Applebaum, A. and Fritsch, P. C. "Zeus 1/XRAM Traffic Control System (Proposal 1)," NOLM 10669, 3 Jan. 1950 (Confidential)
8. Plumley, H. J. and Anspacker, W. B. "Traffic Control for Zeus; General Outline of Problem and Specific Methods Applicable to XRAT Guidance System," NOLM 10581, 10 Nov. 1949 (Confidential)
9. Memorandum from A. Applebaum, NOL, to M. F. Davis, NOL, dated 17 Feb. 1950, "An Important Modification of the XRAM Traffic Control System" (Confidential)
10. Stafford, B. H. "Roll, Pitch, and Yaw of the USS MACON, CA-132 As Measured at Sea," NRL Report 3575, dated 29 Nov. 1949 (Confidential)

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