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NRL REPORT NO. R-3075

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LARK-WASP GUIDED MISSILE SEMINAR

February 1947

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★ Date: 12 DEC 2012

Reviewer's name: A. THOMPSON,
P. HANNA

Declassification authority: NAVY DECLASS
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LARK-WASP GUIDED MISSILE SEMINAR

by

Arthur S. Locke
Project Engineer, Radio Division III

13 February 1947

Approved by:

Dr. R. M. Page
Superintendent
Radio Division III

Commodore H. A. Schade
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"Warp Missile Control System Electronic Components"
Discussion of 25 October 1946 by W. E. Gustaf and
C. W. Hoopes, Radio Division III, WRI.

APPENDIX 2

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Conference

APPENDIX 4

Guided Missile Guidance System, by
Commander J. H. McMillan

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INTRODUCTION

PURPOSE OF PROBLEM A-156R-S, LARK MISSILE CONTROL

The primary purpose of Problem A-156R-S, assigned by BuAer, is: "to modify the SP Shipborne radar and, with a radar beam control receiver, afford radar beam control of the Lark Missile."

The Lark is a subsonic missile operating at approximately 0.85 Mach number. Two versions are under development: KAQ-1 Lark, designed and manufactured by the Fairchild Pilotless Plane Division; and KAY-1 Lark, designed and manufactured by Consolidated Vultee Aircraft Company.

The specifications for the beam rider system provide that the operating range of the system shall be at least 90,000 yards; that the control shall be operable to at least 40,000 feet altitude. The target shall be considered to be comparable to a medium bomber. The SP Shipborne radar shall be modified to incorporate automatic tracking of the target and shall transmit control intelligence to the receiver in the Lark by pulse time modulation.

The receiver shall be dimensioned as required to be located in the Lark; it shall accept and interpret the information received from the radar beam so as to furnish proportional control to the missile to maintain it on the line of sight between the radar and the target.

PURPOSE OF PROBLEM O-126R-C, PROJECT WASP

The primary purpose of Problem O-126R-C, assigned by BuOrd, is: "to develop and test a system for control of a guided missile by means of a radar beam modulated at different frequencies in different lobes."

NRL PLANS FOR DEVELOPING BEAM RIDING GUIDANCE SYSTEMS

The problem of providing beam riding control for the Lark and developing the Wasp system of guidance are precisely similar in basic principle. The NRL plan for developing a beam riding guidance system has been based upon utilization of the implementation specified for control of the Lark missile.

An SP Shipborne radar, using S-band carrier frequency scanned at 24 cps, has been modified to provide pulse time modulated signals to furnish the reference for the airborne receiver. The servo-systems in the SP radar mount have been designed both for better performance and for automatic tracking. The SP mount has been redesigned to reduce undue frictional loading and unbalance existing in the production model of this equipment. The mechanical reworking of the mount in accordance with the changes in the redesign is nearing completion. The modification of the antenna feeds to better the performance of the SP is nearing completion; a similar modification of the antenna feeds of the SP-1M has been completed.

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The SP Shipborne radar, because of weight and other physical restrictions, cannot be considered adaptable for field test use. A truck mounted mobile radar, the SP-1M, differing from the SP only in that the dish is six feet in diameter as compared to eight feet and that no stabilization or cross level axis is provided, is undergoing modification for field test use. In general, the modification of the SP-1M will be delayed until successful test results on modified components of the SP have been completed.

Several designs of the receiver, designated officially as AN/APW-4, have been investigated, tested and discarded. These receiver design considerations have included missing pulse type and various quadrant type receivers. These systems are merely variations of the basic use of pulse time modulation for obtaining reference. By modulating the pulse repetition rate throughout the entire scanning cycle the reference information is sampled with greater frequency. There are no fundamental problems involved in modulating the pulse repetition rate over the entire scanning cycle that are not equally involved in the other systems. Other types of reference systems have been considered; one of them being an extremely stable oscillator running at lobe frequency, synchronized at or immediately before launching. Receiver types have undergone considerable investigation; crystal video receivers have been tested and found unsatisfactory because of low selectivity, microphonics and circuit noise. A receiver of the super-heterodyne type has been flight tested with partial success. A new receiver, designed to eliminate the faults uncovered by these flight tests, is nearing completion.

Preliminary flight tests are conducted with a pilot guiding the plane from cross pointer meters which indicate departure of the plane from the cross-over of the radar beam. It is planned that when a receiver is completed and so tested, and determined to be fully satisfactory in its performance by the preliminary flight tests, it will be connected to a modified auto pilot and used to guide the plane, with the pilot acting only as an observer. An SNB has been equipped with a Bendix P-1 auto-pilot. Components of another P-1 auto-pilot have been modified to receive the outputs from the receivers and to translate these outputs into correct flight response. Frequency response tests are being made of the SNB, used in the test; the modified auto-pilot; and the combination of the two, to permit proper design of the equalizer circuits of the control, thus to insure stability over the parameters of the flight tests. A test investigation of noise, its magnitude and effect is planned. Simultaneously a mathematical study of noise is underway. When successful tests and control flights are achieved, it is planned to start the miniaturization of components and the engineering design of the receiver for the Lark missile.

Throughout the entire development of the beam riding control, it is planned to examine fully all parameters of each phase of the Problem building step-to-step upon known quantities and determined facts. This procedure has entailed studies beyond the original scope of the problem and has clearly illustrated the need for intense coordination of the efforts of the Laboratory with the contractors for the control equipment and the airframe of the Lark, and with the representatives of the cognizant Naval Bureaus.

A beam rider simulator, operating on a 1:1 time scale is being constructed. This is an analogue computer and will be used to examine the dynamic behavior of the airframe and control components in simulated flight, as a closed loop. The simulator may also be used as a tester for some control components. The simulator is designed for use for study of any Wasp type beam rider; it is not limited to the specific problem of control of the Lark.

Many of the problems encountered in the development of the beam riding guidance system are of scope beyond the strict bounds of the assigned problem, but so closely related to the successful conclusion of the project that independent investigations are necessary. In order to disseminate the information obtained as a result of these studies, the major portion of the Lark-Wasp meetings are devoted to the presentation of technical papers or talks on the studies. The studies include: the attenuation and modulation of

signals caused by the propelling flame; the effects of ground reflection on the control line; the magnitude and effects of noise; problems of launching and capture by the guiding radar beam; optimum crossover for a beam rider guidance system; servo considerations for a beam riding airplane and the missiles; tactical problems vs transmission band width and many others. Work on these investigations is continuing; additional studies will be started and similarly reported as the need arises.

The beam riding guidance system is but a part of the Lark control system and its characteristics are dependent upon dynamic behavior of the control elements and the airframe. In order to maintain the close coordination necessary between the Laboratory, the contractors supplying the airframes and control components and the cognizant Naval Bureaus, these agencies have given technical papers or talks upon their problems at the Lark-Wasp Seminars. This has resulted in a clearer appreciation of the magnitude and parameters of the interrelated problems to the mutual satisfaction of contributing groups. Papers thus far presented include "Present Status of Associated Components of the Lark," "Lark Components and System Integration," "History of Flight Control Assembly and Plans for Future Developments," "Stability Considerations of the Lark," "Survey of Pilotless Plane Division of Fairchild Activities on the Lark," "Dynamic Stability of the KAQ 1 Lark," "KAQ-1 Lark Control Systems," and "Shipboard Launching Problems."

SEMINAR MEETING OF 13 FEBRUARY 1947

PLACE OF MEETING

Naval Research Laboratory, Building 27, Room 101.

ATTENDANCE

Laboratory Personnel of Radio Division III:

Dr. R. M. Page	R. G. Bivins
A. H. Schooley	A. E. Adams
P. Waterman	J. H. Campagna
F. M. Gager	J. P. Spalding
J. E. Meade	E. W. Peterkin
C. L. Key	R. L. Timm
L. F. Gilchrist	D. M. Hooper
R. R. Riley	R. M. Jaquess
C. F. White	G. A. Glaubitz
S. F. George	C. M. Morrow
R. E. Gaylord	R. J. Mackey
C. W. Stoops	Dr. L. R. Philpott
	A. S. Locke

Visitors:

F. E. Ellis	BuAer	L. W. Ferris	BuShips
H. N. Precoda	BuAer	G. C. Thom	BuShips
H. E. Oppenheim	BuAer	A. Shostak	ONR
P. H. Girouard	BuOrd	R. O. Larson	APL
G. J. Garmirian	BuOrd	W. A. Good	APL
C. F. Pilger	BuOrd	Comdr. J. H. McQuilkin	BuShips,
D. B. Houghton	Franklin Institute		Code 440

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REPORTS ON PROGRESS

SP Antenna Servo-System: Mr. White reported that the servo amplifier rack has been recabled for the new antenna control amplifier, the added hand crank amplifiers and the additional power supply chassis. The precision alignment unit has been redesigned and the construction of the redesigned units is well underway. The antenna scan control circuits of the PPI chassis have been modified and the installation of these circuits has been completed.

SP Antenna Mount: Mr. Waterman reported that the mechanical corrections to the SP Antenna Mount are now essentially complete.

SP-1M Mount: Mr. Waterman reported that a study is now underway to investigate what mechanical redesign of the SP-1M mount will be required.

SP-1M Pulse Time Modulator: Mr. Riley reported that the SP-1M pulse time modulator has been completed and installed.

Simulator, Mechanical Details: It is estimated that nine weeks will be required for the completion of construction and assembly of the Computer Assembly, the lead Screw Assembly, and the Simulator Cabinet. It is estimated that the construction of the Director sub-assembly will require eleven weeks. Upon the completion and assembly of these components the computer may be used for purposes of checking and testing its operation. The introduction of additional parameters has required modifications to the gimbal ring. It is estimated that twelve weeks will be required to effect these modifications. After installation of these components the simulator will be operable with the assumption of the constant missile velocity. The missile speed computer, to introduce the parameter of the variation of missile speed in flight, is being built by our own shop. It is estimated that this will be ready by the middle of May. The installation of this equipment can be effected without compromising the existing components.

Simulator, Receiver Circuits: Mr. Stoops described briefly the electronic components of the Wasp Missile Control Simulator as developed by the Radio Division III, of the Naval Research Laboratory, for use in conjunction with the Lark and Wasp projects. Mr. Stoops advised report C-F42-1/84(1163:1163/CS), Serial C-1100-427/46, entitled "Wasp Missile Control Simulator Electronic Components, Description of" had been issued on this subject to an internal distribution list, but that it was the present purpose to incorporate the details of the report with the Lark-Wasp seminar report. This paper is Appendix 1 to this report.

Auto-Pilot and SNB Test: Mr. Gaylord reported that the modified P1 auto-pilot has been installed in the SNB. Ground tests of the auto pilot in the SNB are essentially complete. Flight tests to determine the dynamic performance of the P1 auto-pilot and the SNB in flight will be underway in the immediate future.

Receiver Test: Mr. Spalding reported that the most recent design of receiver was now completed and essentially ready for ground testing. In order to accomplish ground test work (inasmuch as the test facilities have been removed from Fort Drum,) the SP-1M is being relocated within the grounds of the Laboratory. When the SP-1M is set up, ground tests on the receiver will proceed. It is estimated that a minimum of two weeks will be required before flight tests can be started.

Signal Attenuation Tests: Mr. Gager reported that the planning phase of the tests to be made at Reaction Motors, Incorporated, was completed. Specifically, the quasi-optical performance of and the incidental modulation produced by a jet constitutes the main study. To this study, supporting measurements are added in the form of sound

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field, light field and vibration measurements, which will be, where required, simultaneously observed for correlation with incidental amplitude modulation observations. Other measurements are to be made, dealing with jet ionization conditions.

In addition, the NRL Optics Division expects to supply personnel and equipment to make spectrographic studies and radiation measurements. The truck - trailer field unit with the necessary equipment is approximately 50 percent assembled at this date, with the remaining 50 percent to be accomplished at an accelerated pace within the next two weeks.

DISCUSSION:

Mr. Carroll L. Key, Jr., of Radio Division III, Naval Research Laboratory, presented a paper entitled "Optimum Beam-Cross Over for Guiding and Tracking SP Radar." This paper forms a part of this report as Appendix 2.

Dr. L. R. Philpott of Radio Division III, Naval Research Laboratory, presented a paper entitled "Considerations of Launching a Beam Riding Missile." A copy of this paper forms Appendix 3 of this report.

Commander J. H. McQuilkin, Code 440, Bureau of Ships, presented a paper entitled "Shipboard Launching Problems." A copy of this paper forms Appendix 4 of this report.

NEXT MEETING:

The next Lark-Wasp Guided Missile Seminar will be held on 13 March 1947 at 1:30 PM, Room 101, Building 27 at the Naval Research Laboratory.

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Gold, light field and vibration measurements, which will be where required, similar-
ously observed for correlation with incident light's radiation observations.
Other measurements are to be made, dealing with jet radiation conditions.

In addition, the NRL Optics Division expects to supply personnel and equipment
to make spectrographic studies and radiation measurements. The track - trailer
field and with the necessary equipment is approximately 50 percent assembled at this
date, with the remaining 50 percent to be accomplished at an accelerated pace within
the next two weeks.

DISCUSSION

Mr. George J. Kay, Jr., of Radio Division III, Naval Research Laboratory, presented
a paper entitled "Optimum Beam-Cross Over for Guiding and Tracking SP Radar." This
paper forms a part of this report as Appendix 1.

Dr. J. R. Phillips of Radio Division III, Naval Research Laboratory, presented a
paper entitled "Considerations on Launching a Beam Riding Missile." A copy of this
paper forms Appendix 2 of this report.

Commander J. H. Moseley, Code 609, Bureau of Ships, presented a paper entitled
"Shipboard Launching Problems." A copy of this paper forms Appendix 4 of this report.

NEXT MEETING

The next East-West Guided Missile Seminar will be held on 12 March 1947 at 1:30
PM, Room 104, Building 21 at the Naval Research Laboratory.

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APPENDIX 1

NRL Interim Report on Problem A-156R-S and Problem O-126R-C,
"Wasp Missile Control Simulator Electronic Components,
Description of." 25 October 1946

by

R. E. Gaylord and C. W. Stoops,
Radio Division III, NRL

ABSTRACT

A description is given of the electronic components of the Wasp Missile Control Simulator as developed by the Missile Control Division of the Naval Research Laboratory for use in conjunction with the "Lark" project.

This simulator will be used in the design and test of various "Wasp" type missile control systems, and particularly the problems encountered in the "Lark" project.

INTRODUCTION

The problem of a beam-riding guided missile is one of many complexities and demands a knowledge of guided missile action beyond that which is available at present. For this reason a system was developed which could be made to simulate the actual flight path of a "Lark" missile flying in a radar beam.

This report covers the design and operational characteristics of the main electronic components of the simulator together with an explanation of the relationship between the simulator components and those of the actual system.

DESCRIPTION OF SYSTEM OPERATION

The two main components of the Lark Missile Control system are a Lark missile receiver and an SP radar modified by the introduction of pulse time modulation. The source, a 30-cycle wave, is supplied by one phase of the lobing generator. Briefly the manner of operation is as follows: As the missile is launched into the beam, the control circuits in the missile are able, as a result of the modulation of the radar signal to determine the position of the missile with respect to the center of the beam magnitude and direction. This information is then used to position the control surfaces of the missile in such a manner that the missile is brought into the center of the beam. Any subsequent divergence of the missile from the beam center causes modulation of the received radar signal resulting in the repositioning of the control surfaces, thus bringing the missile back to the beam center. From this it can be seen that it will also be true that if the radar is used to track a nonstationary target, the missile will be made to fly toward the target along the moving beam.

TRANSMITTER

To simulate the SP radar a 30 Mc transmitter is used. The transmitter, as shown on Figure 1, consists of a Hartley oscillator employing an 837 tube with 1500 volts dc on the plate and 0 volts dc on the screen. The plate tank circuit is tuned to 30 Mc and coupled to a whip antenna. One microsecond 250-volt positive pulses are applied to the screen at an average rate of 620 per second, from the Keyer. These are clamped by a

6H6 to maintain the proper dc level. The 837 then oscillates during the positive period of the pulses.

To produce the 620 pulses per second a non-symmetrical free running multivibrator is used. See Figure 1.

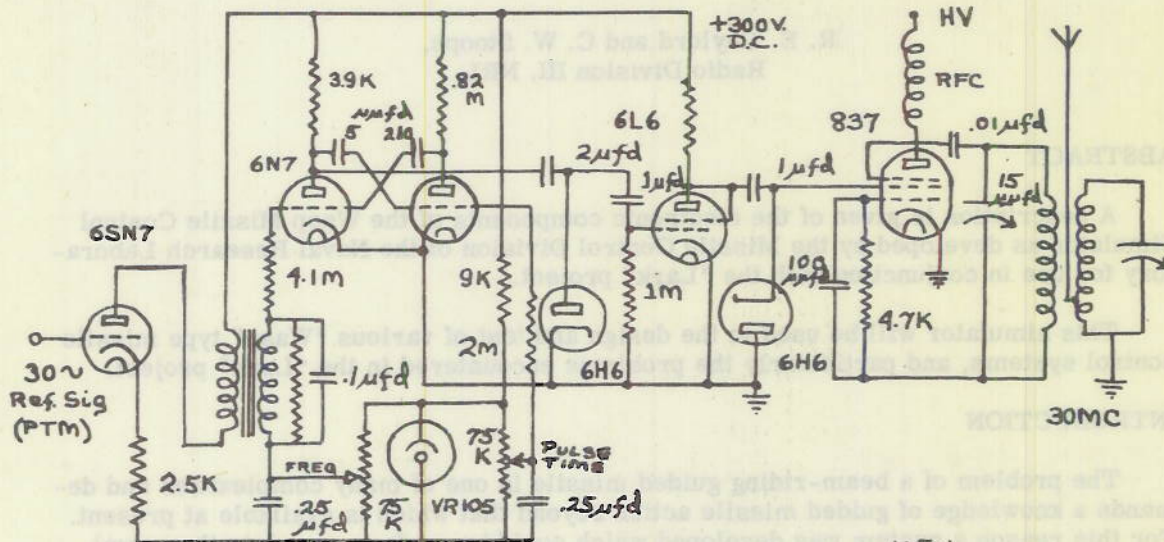


Figure 1

A tube, type 6N7, is used for this purpose. Pulse time modulation of the reference signal is achieved by modulating the bias of half of the multivibrator controlling the repetition rate with a 30-cycle signal from the scanning generator. Stabilization of the keyer is obtained by the use of a VR 105 to minimize line voltage fluctuations. To obtain sufficient amplitude of 30-cycle modulating signal a tube, type 6SN7, is used as a voltage amplifier.

MISSILE CIRCUITS

The circuits of the missile simulator are shown in block diagram form in Figure 2.

Tracing the order of operation of the simulant missile we find first the receiver proper and its attendant circuits as shown in Figure 3. The received signal modulation containing pulse time information is detected by a IN33 (crystal detector) and is amplified by two video stages. At this point in the simulator, amplitude modulation of the signal is introduced. The source of this modulation representing displacement between beam and missile will be described in subsequent paragraphs. The signal is next routed through cathode followers simultaneously to a 100 percent pulse stretcher and to a single kick multivibrator. Considering first the operation of the 100 percent pulse stretcher we find that any particular pulse impresses a charge on condenser "C" which is proportional to the pulse's amplitude. This condition exists until a "clear out" pulse, arriving a fraction of a microsecond before the next pulse is due, discharges the condenser to its steady state value. By this means a continuous wave containing 30-cycle amplitude modulation is obtained. This modulation is a result of the missile being out of the beam center of the conically scanned lobe, the correct interpretation of the information depending

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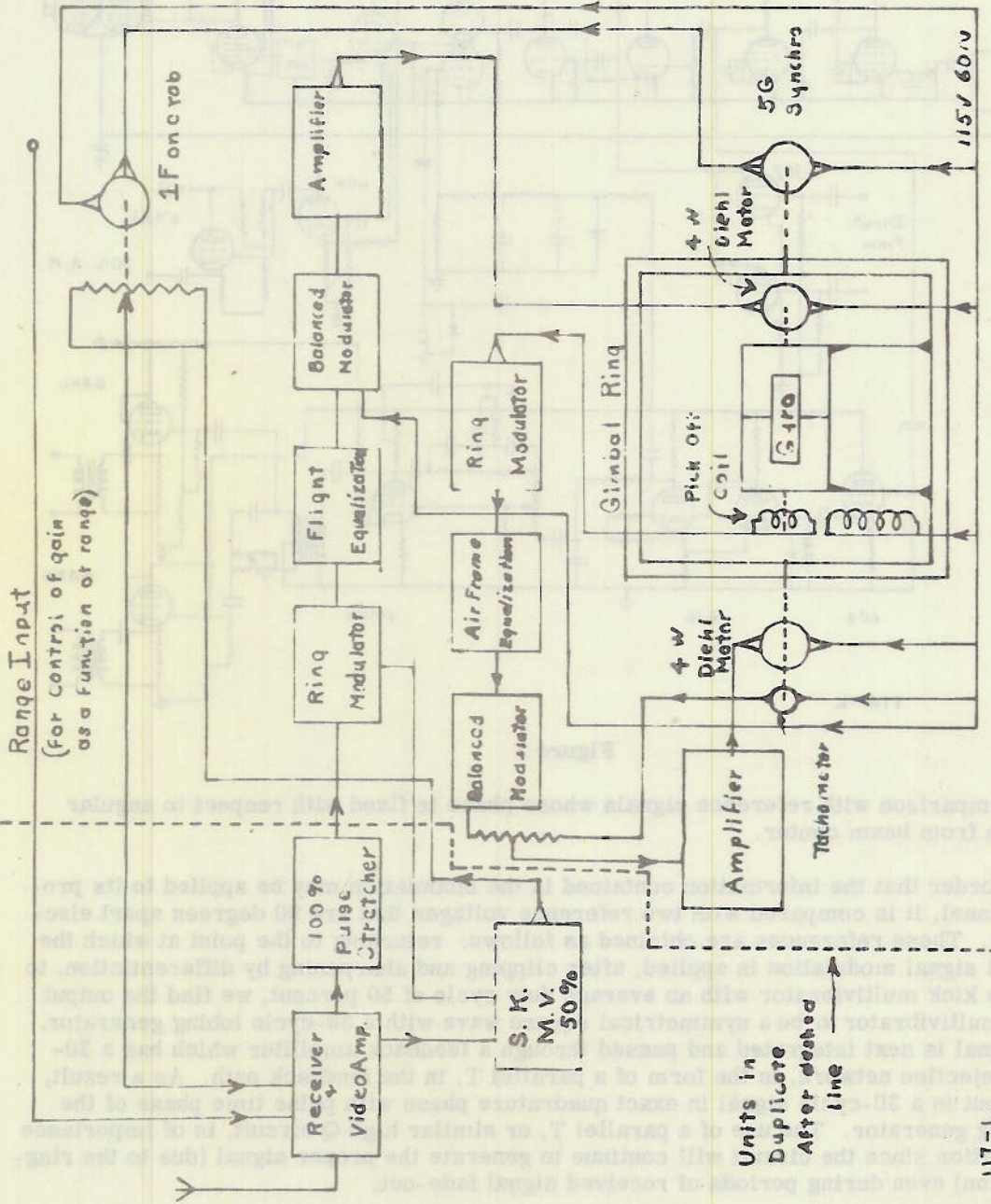


Figure 2

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It is assumed that in the transmitter the scanning generator has been oriented in such a manner that the scanning effectively takes place in phase with the pulse time modulation. This 30-cycle signal may thus be used for one reference in determining the portion of amplitude modulation due to the rotation being out of the beam in either the horizontal or the vertical plane; the actual phase represented depending upon which phase

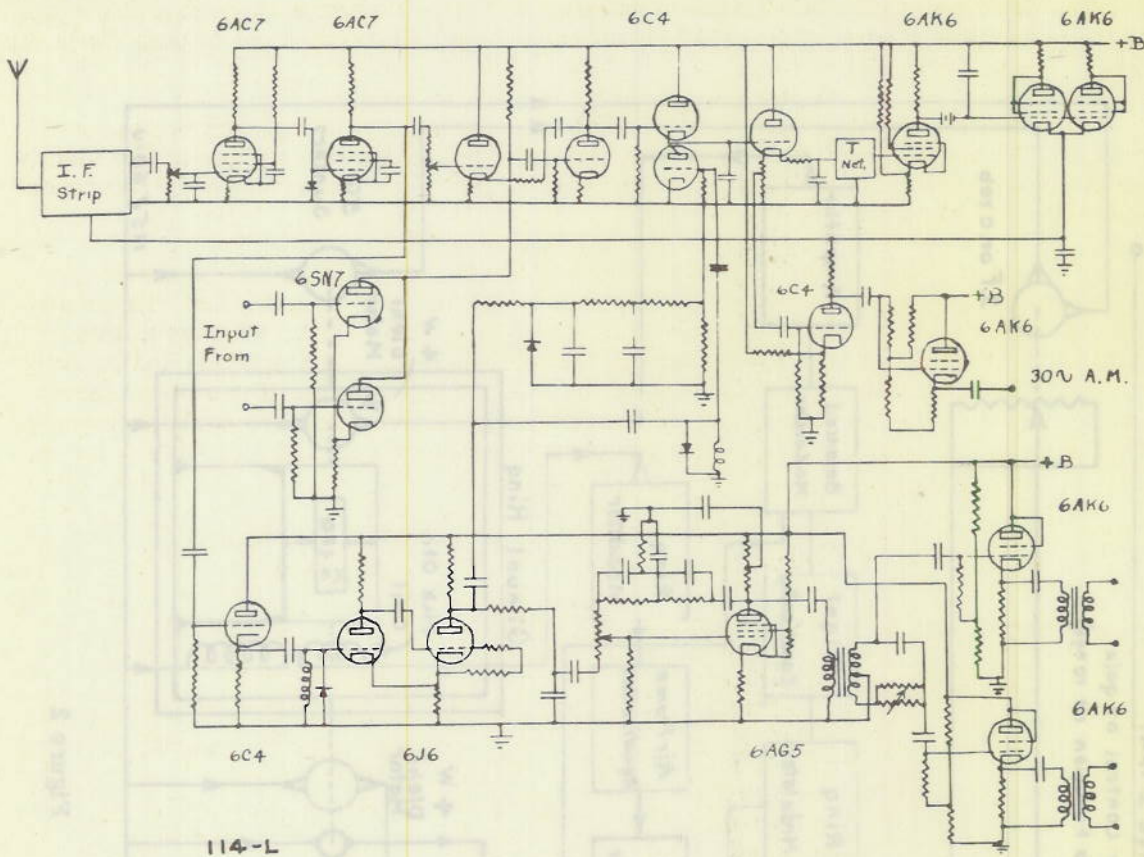


Figure 3

upon comparison with reference signals whose phase is fixed with respect to angular position from beam center.

In order that the information contained in the modulation may be applied to its proper channel, it is compared with two reference voltages that are 90 degrees apart electrically. These references are obtained as follows: returning to the point at which the original signal modulation is applied, after clipping and sharpening by differentiation, to a single kick multivibrator with an average duty cycle of 50 percent, we find the output of the multivibrator to be a symmetrical square wave with a 30-cycle lobing generator. The signal is next integrated and passed through a feedback amplifier which has a 30-cycle rejection network, in the form of a parallel T, in the feedback path. As a result, the output is a 30-cycle signal in exact quadrature phase with pulse time phase of the scanning generator. The use of a parallel T, or similar high Q circuit, is of importance to operation since the circuit will continue to generate the proper signal (due to the ringing action) even during periods of received signal fade-out.

It is assumed that in the transmitter the scanning generator has been oriented in such a manner that the scanning effectively takes place in phase with the pulse time modulation. This 30-cycle signal may thus be used for one reference in determining the portion of amplitude modulation due to the missiles being out of the beam in either the horizontal or the vertical plane; the actual plane represented depending upon which phase

of the scanning generator was used for pulse time modulation.

The other reference is obtained by passing the 30-cycle signal through a phase-splitting network thus producing a second signal equal to but 90 degrees out of phase with the first.

Cathode followers are used to supply low impedance outputs for each "reference" voltage. The separation of horizontal and vertical components takes place in two identical phase sensitive ring modulators, each utilizing one of the above defined "reference" voltages. See Figure 4.

The ring modulator output is dc voltage with polarity varying as the phase of the error signal changes with respect to the phase of the reference signal, and with amplitude varying directly with the amplitude of the error signal. Thus, we have at this point two dc signals, which may be termed "error" signals, with amplitude and polarity a proportional indication of the location of the missile with respect to the beam center. Since the rest of the components of the missile and their functions are correspondingly the same for train and elevation, only one channel will be discussed from this point on.

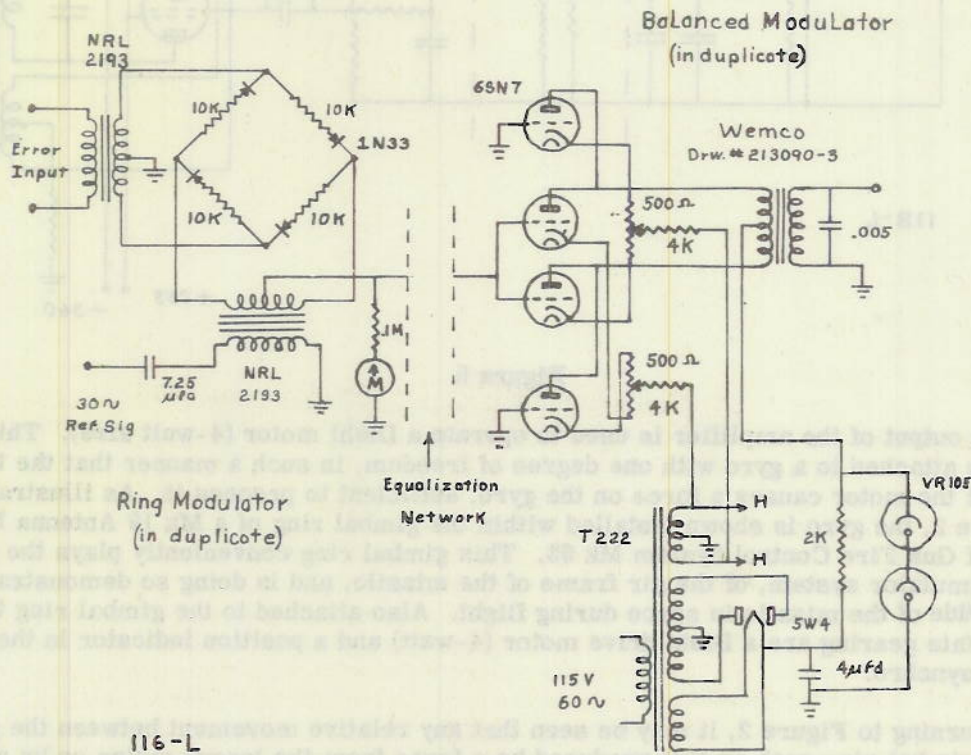


Figure 4

The first step after equalization in utilizing the dc error signals is to convert them to 60-cycle ac voltages in which the phase of the voltage depends upon the polarity of the dc input and the magnitude varies directly with the dc value. This is done by means of a balanced modulator, the circuit of which is shown in Figure 4. Its operation is as follows: the dc voltage is applied to the two ungrounded grids causing one pair of tubes to amplify the 60-cycle signal applied to the cathodes in a manner either greater or less than the other pair; the amount of the differences of amplification depending upon the dc voltage

level and the phase depending upon the polarity of the applied signal. The signal is next applied to the input of a conventional servo amplifier (see Figure 5) consisting of a stage of high gain amplification, an inverter stage, and a push-pull output stage.

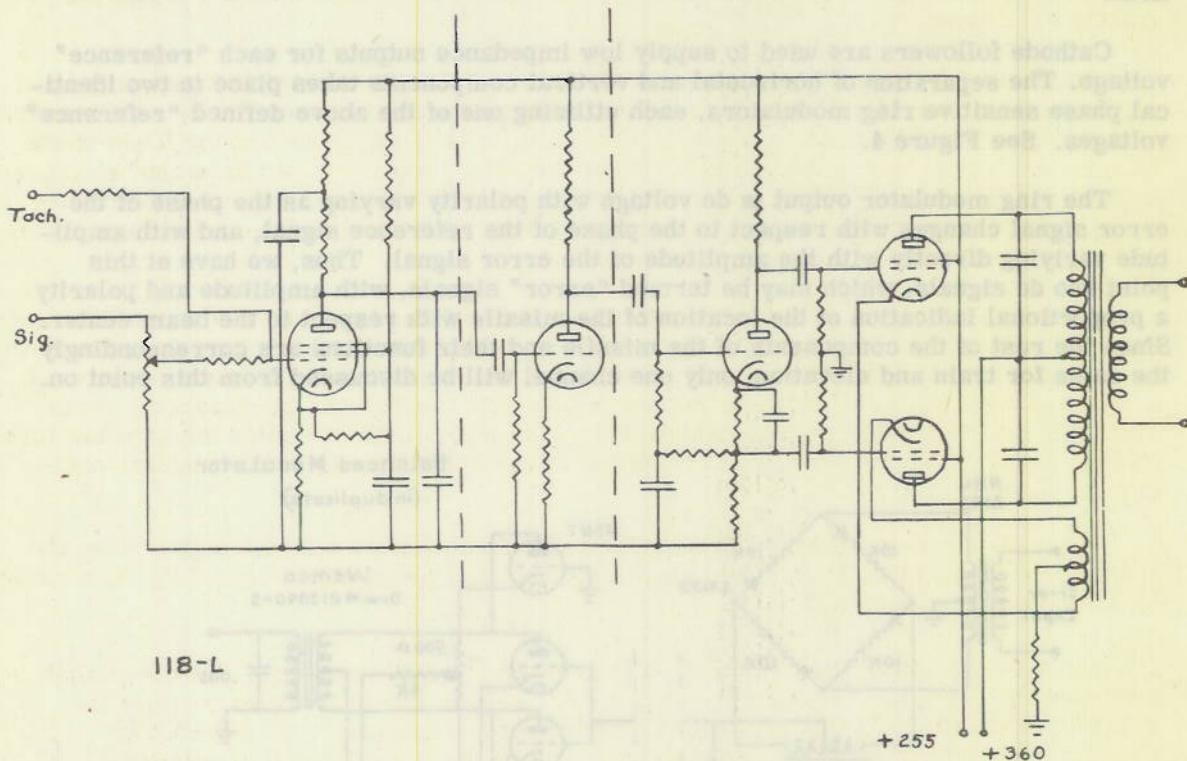


Figure 5

The output of the amplifier is used to operate a Diehl motor (4-watt size). This motor is attached to a gyro with one degree of freedom, in such a manner that the torque output of the motor causes a force on the gyro, sufficient to precess it. As illustrated in Figure 2, the gyro is shown installed within the gimbal ring of a Mk 19 Antenna Mount, a part of Gun Fire Control System Mk 63. This gimbal ring conveniently plays the part in the simulator system, of the air frame of the missile, and in doing so demonstrates the attitude of the missile in space during flight. Also attached to the gimbal ring through appropriate gearing are a Diehl drive motor (4-watt) and a position indicator in the form of a 5G synchro.

Returning to Figure 2, it may be seen that any relative movement between the gyro and the gimbal ring such as that produced by a force from the torque motor or by attempting to move the gimbal ring by means of an external pressure, i.e., external buffeting of missile as it maneuvers in flight, will result in a voltage being developed across the pick-off coil due to precession of the gyro. This pick-off voltage, after having extraneous components removed from it, is applied to the input of the servo-drive amplifier. The output from the amplifier drives the gimbal ring in such a manner that a force on the gyro equal and opposite to the precessing force is set up. When this happens, the "pick-off" voltage returns to zero and the drive motor stops. At this time, the gimbal ring will either have assumed a new position, if the precessing force originated in the torque amplifier, or returned to its original position if the precession was the result of external forces.

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In order that the gimbal may accurately perform its part in the system, it is necessary that its dynamic response be identical to the actual air frame response of the missile. This can be accomplished by the introduction of R.C. networks into the system as shown in Figure 2. In the case of the Lark, preliminary data indicate that the desired characteristics are a velocity overshoot of 5 percent with a time constant of approximately 0.5 second.

As stated previously, the position, or attitude, of the gimbal ring is transmitted at all times by means of a 5G synchro. This position indication is received by a IF synchro located on a "crab" (a plotting device). This crab is utilized to record the flight of the missile over a predetermined course. Since the actual missile position is also simulated by the gimbal frame any inability on the part of the gimbal frame, and subsequently the crab, to follow the prescribed courses, may be determined and used as a feedback factor to bring the missile into the proper position.

As shown by Figure 2, this correction factor is obtained by means of a potentiometer attached to the crab. Since the 30-cycle lobing generator is used to excite the potentiometer any movement of the pick-off arm away from the mid-point of the potentiometer, as a result of the crab's failure to follow the prescribed course, will produce a 30-cycle signal whose phase depends upon which side of the potentiometer center the arm has turned and whose amplitude is directly proportional to the potentiometer arm's angular position off center.

This potentiometer signal will then be used, in conjunction with the signal from its counterpart in the other channel, to amplitude modulate the signal received by the missile circuits. See Figures 2 and 3.

As has been shown, this modulation is then used in such a manner that the gimbal ring, and the crab, will be caused to take a new position and in doing so, remove the cause of modulation. If this process is carried out continuously over a period of time, it is evident that the simulated missile can be made to "fly out" a prescribed course, with visible indication of any inability of it to do so. It will be possible by this method then to actually observe a missile in simulated flight and to study the effect of varying the circuit parameters throughout the system.

RANGE CONSIDERATIONS

A problem which is of prime importance to the "Wasp" type missile control system is that of maintaining a constant gain level throughout the system independent of range. This condition is necessary to insure stable operation of the system, since the servo-loops involved should, for optimum performance, be equalized for certain definite gain levels.

Two natural sources of loss of gain as a function of range are present. First, the loss of gain due to the attenuation of R.F. energy, measured at the missile, as a result of increasing range. By means of the following equation:

$$\frac{K P_t}{4\pi r^2} = P \quad (1)$$

when K = Transmitter antenna gain

P_t = peak power

r = range

P = received power,

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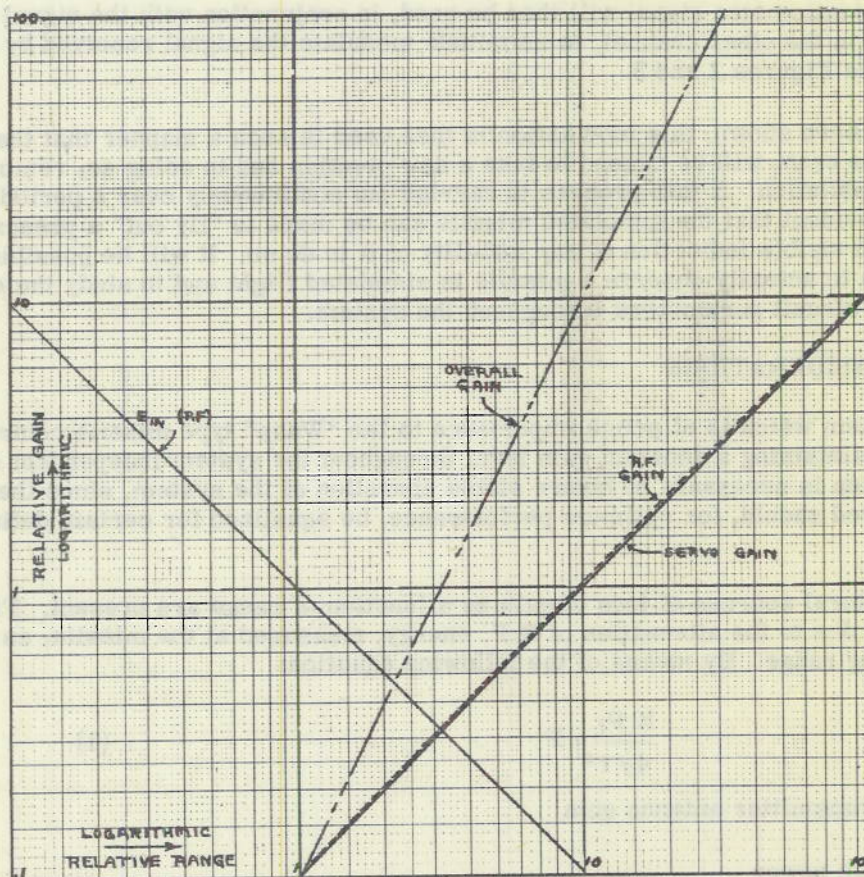
this loss is found to be a direct function of range, falling off at a rate of 20 db/decade. See Figure 1, $E_{in}(RF)$.

Secondly, there is a loss of gain, as reflected by servo stiffness, due to the geometry of the beam pattern of the radar. The pattern is conical in nature with the apex of the cone located at the radar transmitter. For that reason, it may be seen that the ratio of error voltage per unit deviation from beam center will vary directly with range. The continued ratio of the two produce an effective system gain attenuation of 20 db/decade.

To restore overall linearity to the system, it is then necessary to cancel the effects of these two gain characteristics by introducing into the system their inverse functions.

This can be done by using an automatic gain control circuit, since increasing the gain of the R.F. unit as a function of range (see Figure 6) holds the output of the unit constant. The AGC voltage is then used to control the gain of the servo loops (Figure 1, Servo Gain), in such a manner as to make it increase with range at a rate of 20 db/decade.

As a result, the two receiver characteristics combined produced an increasing overall receiver gain (Figure 1, Overall Gain), of 40 db/decade which effectively cancels the original conditions thus producing Overall System Gain linearity, independent of range.



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Figure 6

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APPENDIX 2

Optimum Beam Crossover for a Guiding and Tracking SP Radar

by

Carroll L. Key, Jr.,
Mathematical Consultants Group, Radio Division III, NRL

The determination of the optimum crossover for a conical scan radar designed for tracking a target and guiding a beam-riding missile, simultaneously, involves the consideration of several apparently incompatible parameters.

First, for the maximum reliable "pickup" range of the radar, it is desirable to have as small a scan angle as possible.

Second, for accurate linear tracking, a wide scan angle is needed for target discrimination and following.

Third, since the beam-riding missile follows only the one-way antenna pattern, a rather wide scan angle is desirable for high modulation sensitivity.

In order to arrive at some reasonably accurate idea of the variability and linearity of these parameters, an actual SP radar pattern, as measured by the Beam Rays Section of Radio Division III, was used and graphs made for both one-way (Figures 7-14, pp. 17-19) and two-way modulation envelopes (Figures 15-23, pp. 19-21) for various scan angles and various error angles. Examples of these plots are included. Although the plots show that small error angles give almost pure sine wave modulation envelopes, they also show that wide departures from pure sine waves are easily obtained with moderate and large error angles. As the sense-circuits and servo-circuits follow only the fundamental lobing rate portion of the modulation envelope, it was necessary to run an harmonic analysis for each value of the error angle and for each crossover value. Fortunately, no phase shift was apparent, showing that the sense given by the modulation was correct.

Various plots of the percentage fundamental (or first harmonic) modulation versus error angle were made for both the one-way and two-way cases, showing the linear regions which can form the basis for the selection of an optimum crossover point when the reliable range consideration is also taken into account.

A limitation of the use of these data lies in the fact that they are invalid above the level of receiver clipping. The clipping points are indicated on all graphs, under the assumptions that the receiver a.g.c. stabilizes on average signal level and that the a.g.c. level is set so that the average signal represents 50 percent saturation. As pure sine wave modulation is not present, this clipping level does not represent 100 percent modulation, but rather, somewhat less than 100 percent. A plot of reliable range pickup versus two-way crossover in db down (which is twice the one-way crossover in db down) is included.

The following assumptions were made in the course of development and computation:

Assumptions on the radar:

- a. Conical scan-SP radar
- b. Receiver noise figure 12 db (normal S band)

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- c. Antenna gain 32 db
- d. Wave Guide losses 0.5 db
- e. Indicator, duplexer, and other one-way losses 4 db
- f. Reliable range on single small aircraft, with 3 db two-way crossover, 44,000 yds.

None of these assumptions affects the expected solution for a conical scan type radar, since proportionality factors can be introduced to fit any case.

Assumptions in calculations:

- a. That the amplitude of error signal sent to the servo-mechanism is directly proportional to the fundamental envelope percentage modulation.
- b. No low angle effects are included.
- c. The sensitivity of the receiver in the missile is always sufficient to have adequate power for the missile a.g.c. to maintain control, as long as it is possible to track the target.
- d. The a.g.c. systems in both the missile and the radar are good enough to keep the average signal level constant over a single scan.
- e. That the SP antenna pattern is symmetrical.

Conclusions.

It can be seen that both the one-way and the two-way percentage modulation versus error angle plots are linear in the neighborhood of zero error angle and that both are relatively linear around -3 db crossover (-1.5 db one-way crossover), with the larger crossovers giving more deflection sensitivity when receiver clipping occurs at smaller error angles.

Determination of the actual optimum crossover for any particular application demands merely the selection of the best point which takes into account all three parameters already mentioned and the application of common sense according to the demands and limitations introduced by the case in question.

If equal weight is given to both range and modulation sensitivity, then it appears from Figure 24, p. 22, that the optimum crossover is about 1.8 db down for two-way pattern. However, it must be pointed out that the "supply and demand" type of reasoning is not necessarily valid in the present case. Obviously, in power plant design, there is an optimum when supply is equal to demand. For the purpose at hand, it may be desirable to sacrifice some range in order to gain better tracking. From this standpoint, the usual -3 db crossover commonly used seems to be in the right direction, giving better discrimination although less range.

The present study has progressed thus far, without taking into account the very considerable problem of noise. The results are accordingly without complete practical meaning. This deficiency, according to plan, will be supplied by the noise study now under way.

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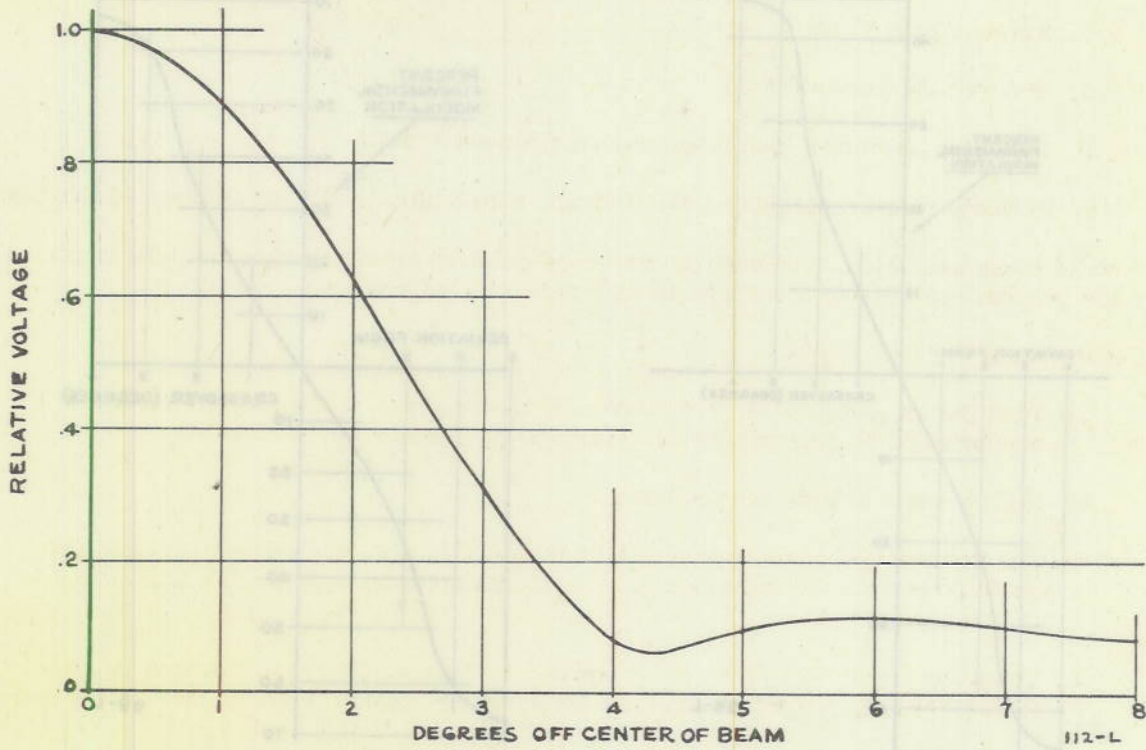


Figure 7. SP Radar Antenna Pattern (One-Way) "H" Plane

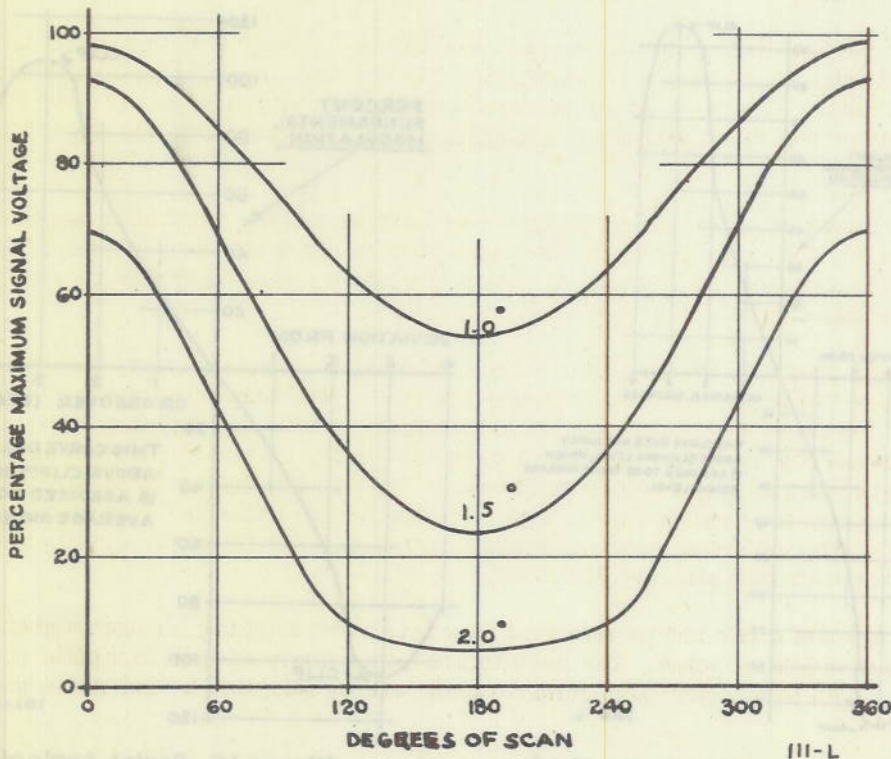


Figure 8. One-Way Crossover (1.5 db Down)

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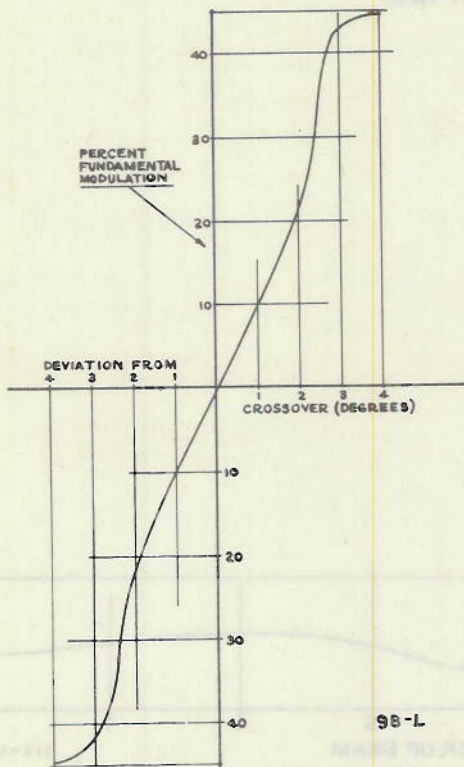


Figure 9. Squint Angle of 0.43° ; (0.25 db) One-Way Crossover

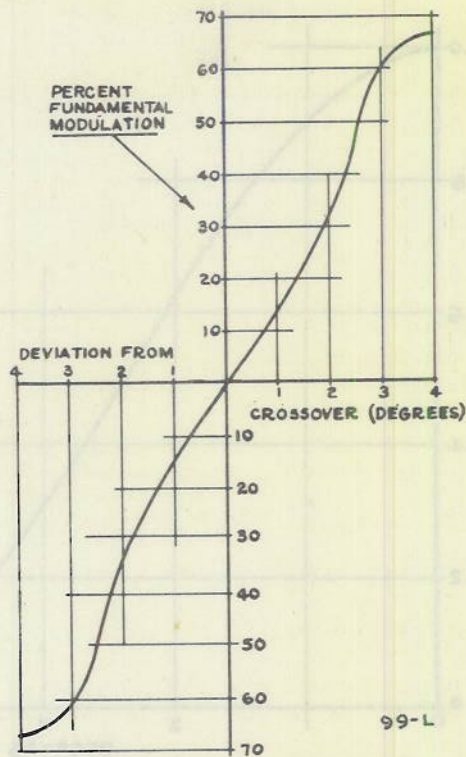


Figure 10. Squint Angle of 0.65° ; (-0.5 db) One-Way Crossover

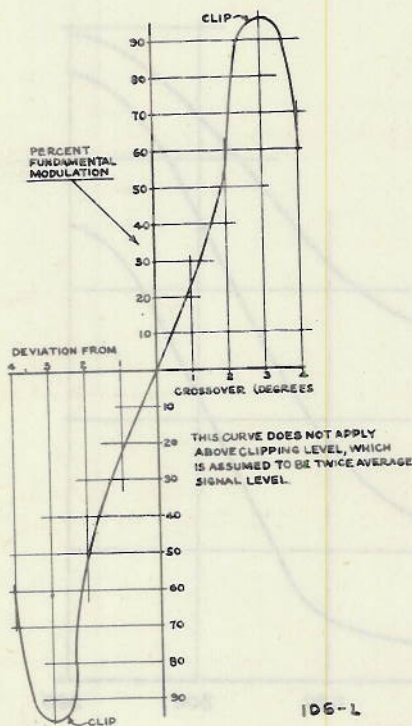


Figure 11. Squint Angle of 1° ; (-1 db) One-Way Crossover

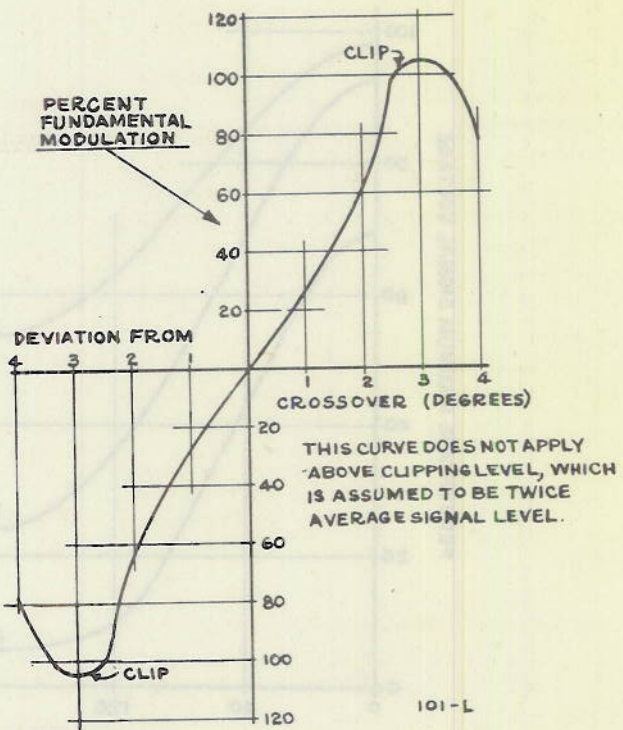


Figure 12. Squint Angle of 1.25° ; (-1.5 db) One-Way Crossover

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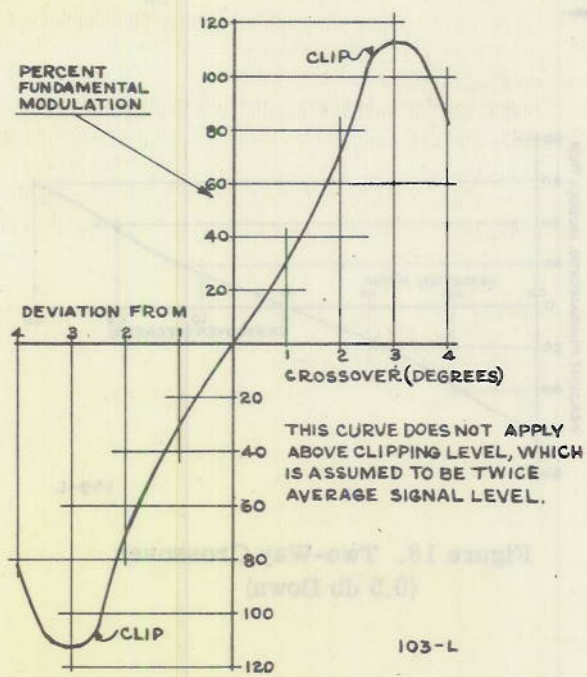


Figure 13. Squint Angle of 1.43° ; (-2 db) One-Way Crossover

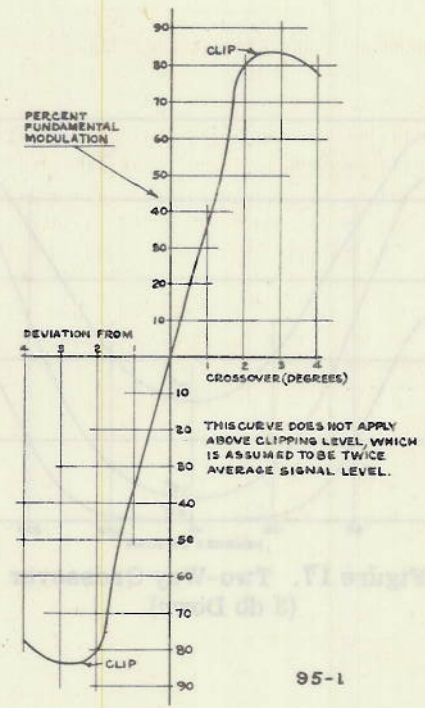


Figure 14. Squint Angle of 1.6° ; (-2.5 db) One-Way Crossover

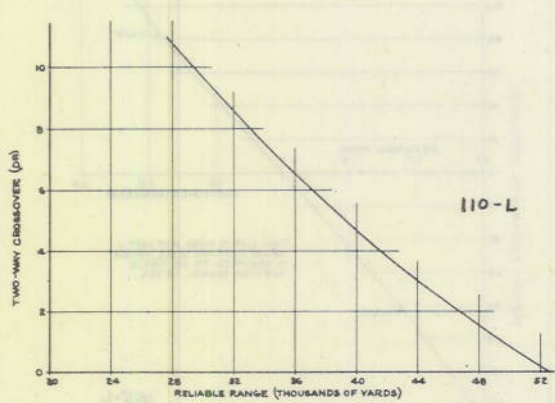


Figure 15. Reliable Range of "SP" Radar as a Function of Crossover

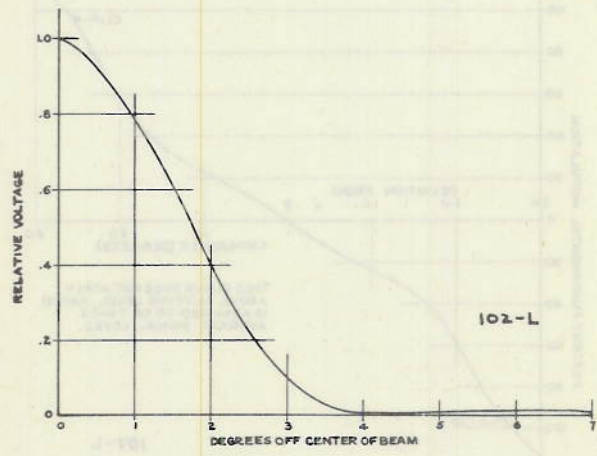


Figure 16. SP Radar Antenna Pattern (Two-Way) "H" Plane

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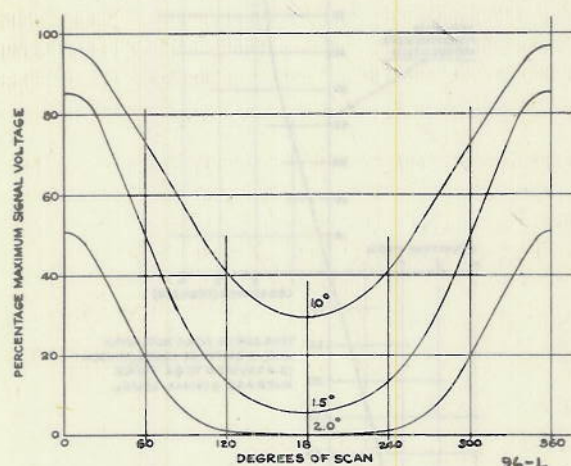


Figure 17. Two-Way Crossover (3 db Down)

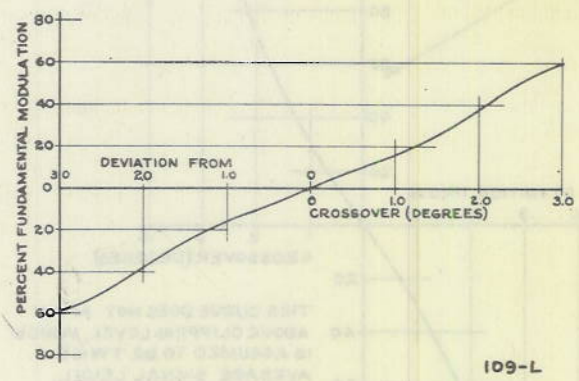


Figure 18. Two-Way Crossover (0.5 db Down)

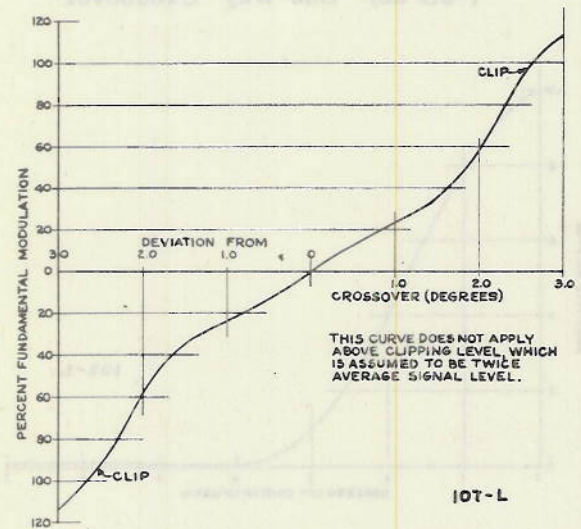


Figure 19. Two-Way Crossover (1.0 db Down)

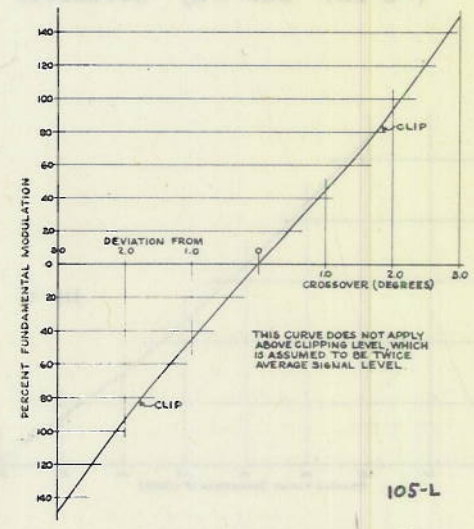


Figure 20. Two-Way Crossover (2 db Down)

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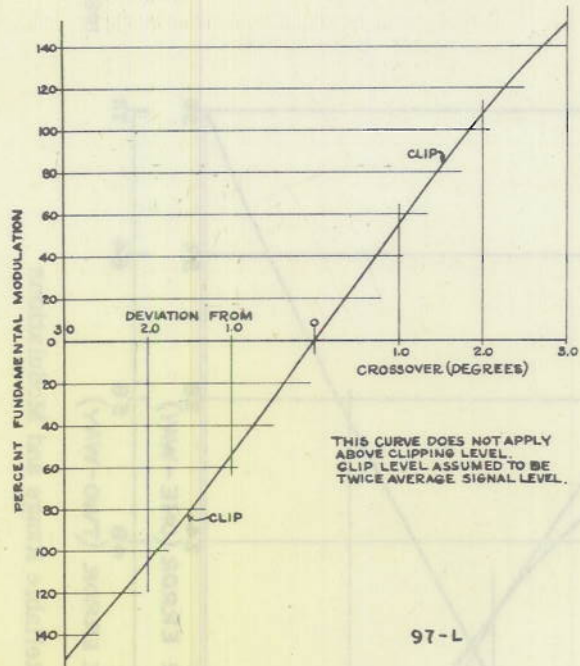


Figure 21. Two-Way Crossover (3 db Down)

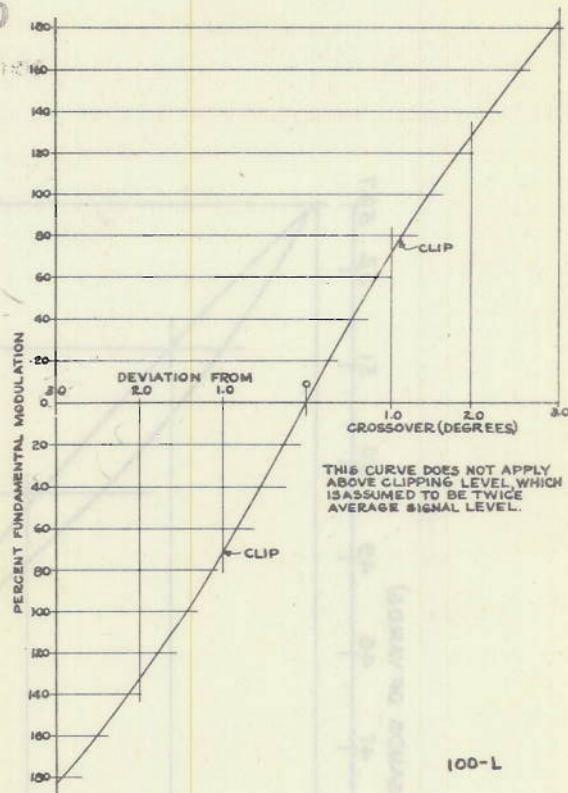


Figure 22. Two-Way Crossover (5 db Down)

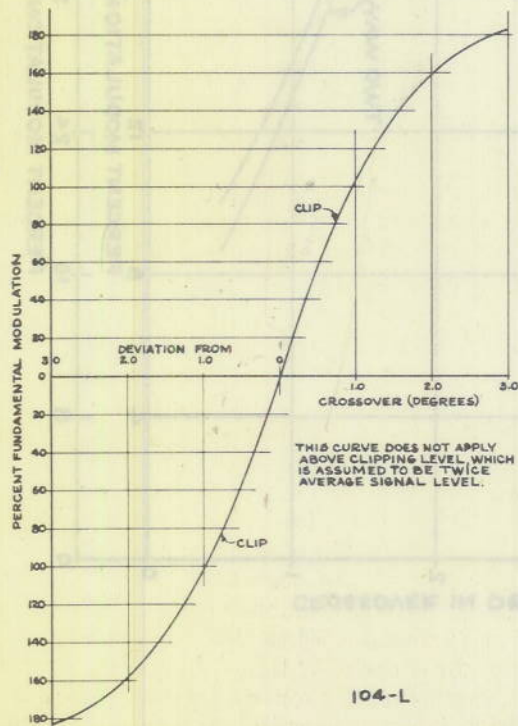


Figure 23. Two-Way Crossover (8 db Down)

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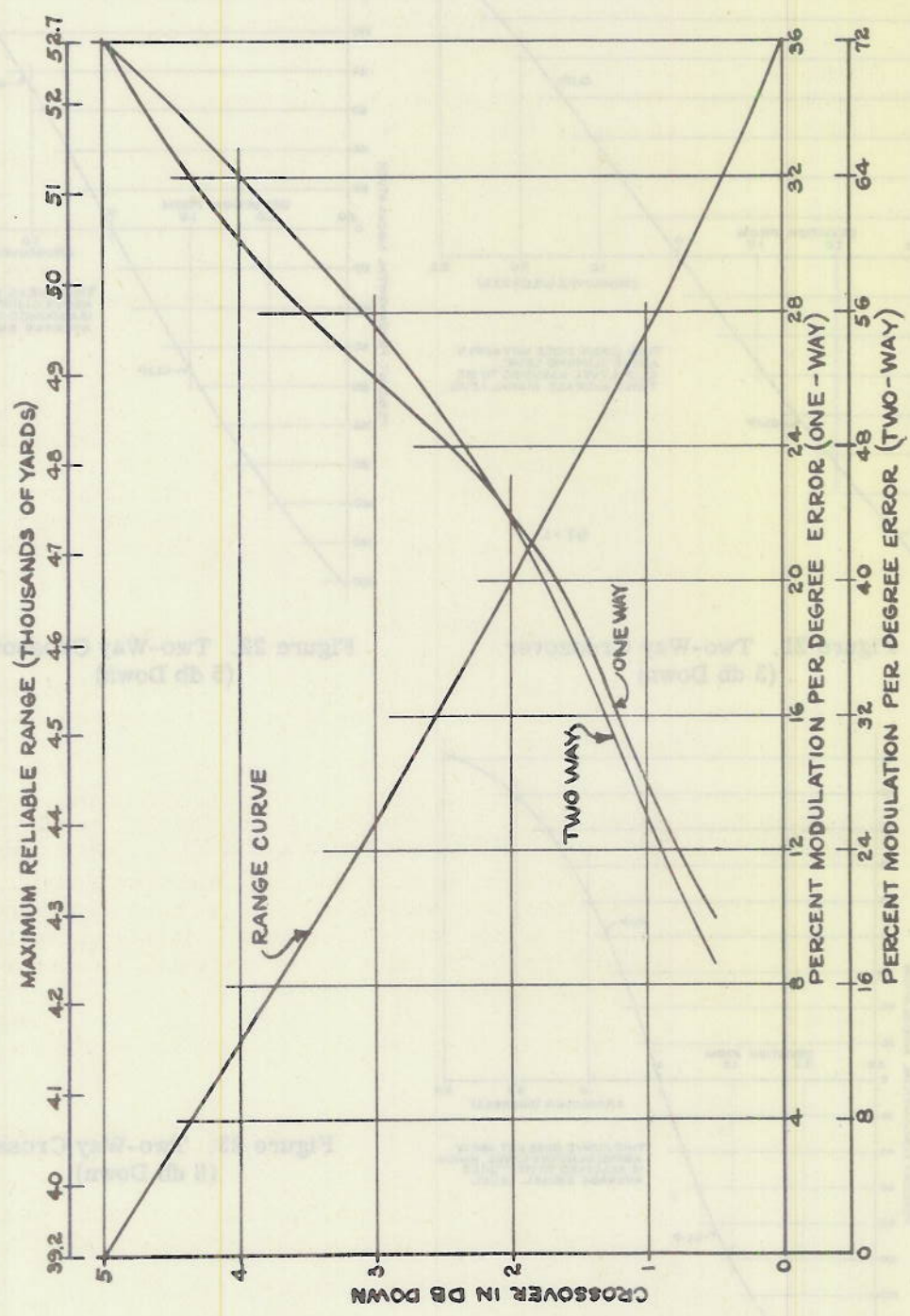


Figure 24. Relationship Between Maximum Reliable Range and Modulations

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APPENDIX 3

The Launching of Guided Missile and Pilotless
Aircraft from Surface Vessels

BASIS OF DISCUSSION BY L. R. PHILPOTT AT LARK CONFERENCE

The choice of a launching technique for any guided missile or pilotless aircraft is determined by the consideration of a number of specialized circumstances. Of these some of the more important ones are:

- (a) The physical characteristics of the launchers, such as: length, width, weight, deck clearance, azimuth maneuverability, elevation maneuverability, location relative to guiding radar antenna, traffic handling capacity with respect to speed of loading, battle damage control,
- (b) difficulty in effecting radar beam capture, involving the study of the length of time of the shepherding interval (that is, from the time of launching to the time of the beam capture). This is one of the most important items. It includes the evaluation of launching doctrines as to whether fixed azimuth launchers or maneuverable azimuth launchers shall be utilized, as well as many other basic determinations such as the use of assisted catapults, JATO units, unassisted jet takeoffs, gun launching, etc.,
- (c) the effect of the use of different fuel combinations on: own ships personnel, difficulty of storage and handling, battle damage control, time required for fueling missiles during operation of loading onto launchers, possibility of storing fuel in the missile while in stowage, corrosion of missile components and ship components during storage and firing,
- (d) the damaging effect of falling booster frames or cars on own ship or nearby ships in fleet,
- (e) the traffic handling capacity of the guiding radars as to whether missiles require individual shepherding into the main control beam, or will follow a relatively broad beam which is fixed with relation to the main beam, or are fired directly into the main beam by the aid of proper computing aids as used in standard fire control equipment,
- (f) the effect of launching angle both in azimuth and elevation on total fuel consumption and time of flight,
- (g) the probable damage to nearby ships due to impact by missiles launched to extremely low elevation angles,
- (h) the number of launching sites on a ship, the rate of fire of each site and the number of such equipped ships necessary at a single location to ward off saturation aircraft raids.

It will not be the intent to exhaustively examine these considerations as there is at this time insufficient information concerning many of the items. The services cannot crystallize their specifications due to the early stage of the art, and until the various developmental agencies are able to get the answers to many questions it will be impossible here to more than indicate some of the difficulties that must be looked for and overcome before successful service use of guided missiles as an effective tool will be realized.

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There are three types of launchers seriously proposed for shipboard installation within the near future, namely:

- (a) 50-foot ramp
fixed, inclined, for submarines with JATO; maneuverable 360 degrees azimuth-60 degrees elevation with slotted gun and JATO for ships.
- (b) Zero or short rail launcher in multiple banks for ships. Completely maneuverable.
- (c) Vertical Launchers with medium length rails.

In addition there is contemplated a number of installations of stabilized launching platforms capable of having any type launcher installed thereon for experimental purposes. Of the above listed types the first is most advanced and a number of installations are concretely under consideration.

For immediate experimental purposes it is quite satisfactory to adapt some present ship for gaining launching and guiding experience, as is being done at present, but if the use of guided missiles is to be considered seriously it will be necessary to design the ship itself around the weapon it is intended to use most effectively. Obviously it would be easier to install more 50-foot launching ramps if they could be fixed in both azimuth and elevation than if they must be completely maneuverable. Unfortunately, as will be determined later, it will be necessary to make them trainable throughout as much azimuth angle as is possible at present with the main battery, and in addition it is advisable to have considerable freedom in elevation depending upon the capabilities of the particular missiles being fired. With these limitations the 50-foot ramp will be eliminated from all but the larger capital ships. The main example of what can be done with a fixed ramp is the case of the submarine launchers. Here the consideration of getting at least one missile launched at any cost outweighs any handicaps that attend such an installation, mainly the extreme low rate of fire, and the necessity of heading the vessel in the direction of launching.

It is extremely important on board ship to locate all launching sites so as to have them easily accessible to the storage magazines. This consideration alone will limit the maximum number of locations.

Each site will require the exclusive use of at least one guiding radar antenna site. In consideration of the difficulties of beam capture, as will be discussed later, it is desirable that no time at all be allocated to the business of shepherding the missile into the guiding beam. This therefore demands one of two possible layouts. The guiding radar antenna may be mounted directly on the launching mount in which the missile is thrown into the beam at once, or it may be mounted at a not too distant point, to be determined by the geometry of the problem with respect to the maximum allowable angle of misalignment of the trajectory of the missile and the axis of the radar antenna. In the latter case the exact angle of the mount must be controlled by a parallax computer which takes into account the different locations of the radar antenna and launching sites. If in addition it is decided to employ an additional radar to shepherd the missile into the beam it will be necessary to enlarge the antenna mount to accommodate a second unit capable of independent control or find a new location for it. This will practically double the demand for available positions for this service. It will be impossible to dispense with the long range search radars.

It seems that there is little possibility of loading the launching device without some elaborate power operated equipment which may require the elevation angle to be returned to a fixed predetermined value, probably in order to align portions of the ramming mechanism. The speed of loading will not immediately be a limiting consideration, but it is

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hoped that all other preliminary operations necessary for the preparation of the missiles for launching will be so perfected that the only limiting time consuming operations will be those of actually ramming the bird into position and setting the launching angle. The ultimate rate of fire from a single launching installation is going to be critical.

It would be unrealistic to consider any launching installation without also considering the problem of damage control. Any object will be subject to damage in some degree depending upon the shape and stiffness of the parts exposed to blast. For instance, a broad solid girder type of construction as used in some railroad bridges is very vulnerable to this type of damage. Round shapes as gun barrels and open structures are better streamlined and stronger and will therefore be better adapted for the purpose. The XM2 slotted cylinder catapult is an example of this character, as the broad solid beams are admirably suited to be twisted by a near miss. Once they are sprung it would be impossible to make repairs other than complete replacement. At this stage of development there will be little need for considering this part of the overall problem as there will be no battle damage in the next few years.

From the viewpoint of structural simplicity and difficulty of control of the launching mount, the fixed ramp has considerable appeal, and many have longed for this solution of the problem. The logistics for this type of installation are simple and a higher rate of fire may thereby be attained. When the possibility is presented to the guidance personnel the story is altered. All missiles would be initiated in a single direction with respect to the ship and would therefore be easy to capture in a shepherding radar beam, but it would also be true that a separate radar would be necessary for each missile on its way into the main control beam at any one time. For the worst case there may be as many as twelve or fourteen on the way into the beam at any instant, requiring as many radar equipments, sites and operating crews simultaneously for each launching site, all under the direct control of the control officer or officers assigned to the particular operation. In addition to the possibility that many missiles would not survive the ordeal of taking so much time for beam capture (up to two minutes) many missiles would be wasted due to the previous destruction of the target by one of the early missiles as signed to that particular bogie. This would necessitate the reassignment of the remaining birds to other targets, a task difficult and often tactically impossible, as many of them would have traveled too far in the wrong direction to be redirected to negotiate a second target. The reason for the missile taking such an inordinate amount of time is a simple one, though often hard to visualize. Basically it resolves itself into the problem of the interchange of functions. In an ordinary piloted aircraft there is the well known effect of interchange of function between the rudders and the elevators when the craft is in a tight bank. A somewhat similar condition exists with the missile when it becomes necessary to shepherd it around the arc of a circle, the center of which is located at or near the guiding radar antenna site. The interchange in this case is between the right-left controls and the speed control. The latter is at present not under the control of any guiding operator and can give considerable concern to any one charged with the responsibility. To visualize the situation better, consider that the missile was designed to be controlled best when it is traveling away from the firing site. In this direction the bird is stable in the sense that if it is, say, too far to the right, as viewed by one at the firing location, it is in a portion of the beam which gives an order to the missile to proceed to left. Also if it is too high, the order is for it to come down. In other words any position which it might assume which is different from what was intended for it will result in orders being communicated to it to correct its position satisfactorily. It is seen that the speed of the missile as such is of secondary importance so long as it remains within reasonably close limits prescribed by aerodynamic and not control conditions. Now, place the bird in the situation of having to follow the arc of a circle as described above. If it should be too high, it will be located in the upper half of the radar beam as before and will therefore receive an order to come back down. In this respect its operation is normal and no difficulty will be experienced. But see what happens when the missile is to the left of the center of the controlling radar beam. The

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direction of travel of the bird is arbitrarily going from left to right. In order for the position error to be corrected it will be necessary for the missile to travel faster to catch up to the position at which it should be. But, as was previously stated, speed is not one of the parameters under the control of the guiding radar and instead of getting the chance to increase its speed which it cannot do, it is given the order to turn hard right rudder since it is in the left hand side of the radar beam. The missile obediently turns its rudders, veers off into a tight turn and is lost. In general, the lesson to be learned from this example is that it is extremely important that a missile at considerable distance from the firing site not be asked to maneuver too rapidly so as to put it in an attitude where there might be an appreciable interchange of control functions, especially when one of them is speed. This is one of the main considerations which limits the reassignment of unused missiles which might be already on their way towards a target destroyed by one of its predecessors.

It is dangerous to require a missile to perform under conditions such that there is an interchange of control function of axes, generally referred to as "cross-talk", of more than 50 percent, or where the effect of control order is felt as much in an axis not being controlled as it is in the desired axis. There are a number of situations where this condition might exist. One of the most common is that where the normal horizontal axis of the bird rolls over until it makes an angle with the real horizon of 45 degrees. In this condition a received order to turn upward will result in a motion which has as much real motion to the side as it does vertically.

Now we have the real case against the fixed azimuth launching ramp. Since we have arbitrarily stated that we do not wish to have a cross-talk value greater than the original order, it will become impossible to shepherd a missile on any curve which approaches a concentric circle closer than an Archimedes Spiral with an angle of 45 degrees between the missile heading and the radius vector from the missile to the guiding site. As it becomes necessary to bring the missile direction progressively different from the direction of the launching ramp by a value approaching 180 degrees the length of time consumed in following such a course, the minimum range at which a target can be negotiated under these extreme conditions, and the increasing danger of losing it altogether due to a too anxious or ambitious radar operator, all indicate the advisability of eliminating the fixed ramp from competing with other mechanisms or installations except in very special cases where there is no real choice, as in the submarine launcher. If one is to consider the advisability of choosing between a ramp which is fixed in azimuth but able to be elevated and one which is fixed in elevation but can be trained, there is little doubt as to the proper choice, as it is much easier to live with a fixed elevation angle than it is with a fixed train angle.

One method being employed for launching missiles, designed particularly to avoid all this difficulty, is that of launching vertically. At once it is seen that it is equally as easy to send a missile in one azimuth angle as it is in any other. In addition, the amount of deck space consumed by the device is minimum and there is no need for elevation angle manipulation either during or between firings, so that missiles could be fired as fast as they could be rammed into place. This system requires a rudimentary navigating device which will bring the bird from a vertical attitude to a horizontal one headed in approximately the correct direction. It can then be picked up by a rather broad radar beam, in the vertical plane, which would gradually lead it into the main control beam. This has another dubious advantage in that all the empty rocket booster bodies and carriages will fall on the firing site instead of all over the earth. An interesting sidelight on the seriousness of this situation can be had by realizing that the terminal falling velocity of these objects is of the order of magnitude of 800 ft/sec at which speed each pound of weight will have about 10,000 ft-lb of energy, which it will all too willingly impart to any object attempting to stop it. With a maintained high rate of fire this aspect itself becomes a serious one. One must therefore decide to construct the launching sites to withstand such impacts as a matter of course, or consider abandoning the use of

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boosters as a means of launching. There are other methods which can be successfully utilized under certain conditions. If, however, it is found that it will be impossible to dispense with rocket boosters, the problem of impact damage can be lessened by the use of parachutes on the frames.

While in some respects this method of launching offers some very attractive advantages it also presents some serious difficulties. Air at higher altitudes is thinner than air at sea level, so from the point of view of resistance to the missile during flight it would seem advisable to have it travel the bulk of its horizontal distance to the target at as high an altitude as possible and thereby save fuel and obtain a longer range. For this one consideration, this is quite true. It must be considered, however, in connection with other aspects of the problem. For the case under immediate surveillance, that is the short-range anti-aircraft missile, this phase is not a controlling item in the choice of a trajectory for the missile. Occasionally it becomes necessary to negotiate a target at a comparatively short range and at a low altitude. In one case, it was shown that it would not be possible to destroy an enemy at low altitude within a distance of 10 miles by this method. ² With a maximum range of the order of 40 miles the overall effective fire power is considerably reduced. While it is true that it requires less fuel to propel a missile at high speed at high altitude as compared to the demand at low altitudes, it is not true that a missile can maneuver at high altitudes as economically as it can at the lower ones. This is because the "bird" is required to execute the same degree of agility at any height. At high altitudes it requires a disproportionate amount of control flap deflection as compared with what it takes in denser air. The drags developed as the direct result of larger control demand require an expenditure of more fuel to effect the same degree of curvature at high altitudes than at low. Using the Lark missile as an example, the amount of fuel consumed per second while negotiating a curve with a radius of curvature of 6000 ft at the speed of 800 ft/sec was calculated to be,

2.64	pounds per second	at sea level
2.46	" " "	at 10,000 ft
2.63	" " "	at 20,000 ft
3.89	" " "	at 30,000 ft

This type of launching imposes some rather difficult requirements on the missile with respect to its getting into the guiding beam. The answer proposed to this problem² has been to utilize a shepherding radar with a rather narrow beam pattern in the horizontal plane and an extremely broad one in the vertical one. The missile must have a program sequence built into it so that it would not misbehave before it actually has been captured by the main beam. To date there has not been very much success in controlling the early trajectory of missiles by this type of launching. The dispersion of the azimuth angle among various firings has been so great that it is too early to form a judgement as to whether launching in the vertical will ever be practical. One of the main difficulties lies in the fact that the radar beam itself is not a simple geometrical pattern, but is made up of what is generally considered as the main crossover beam out which the missile is supposed to travel, and also immediately surrounding it, in most cases, are false beams, so called because the orders delivered to the missiles in these areas are reversed in sense, thus causing the missile to drive itself out of the beam instead of bringing it back in as it should. One of these lies on each side of the main beam, within a few degrees of it, in which the right and left hand signals are reversed, and one lies above and below at about the same separation in which the up and down orders are reversed, and this is not all. Beyond these are more control lines of weaker intensity alternating between true and false courses until by sheer force of the directivity of the antenna structure, the energy in them is less than what would be necessary to successfully control a missile at any considerable range. In addition to all this, when the guiding radar is directed at very low elevation angles, say of the order of the beam width itself, reflection of the energy from the earth makes even the main beam unreliable in

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elevation angle, and this is not even the end. Should the missile momentarily become lost from the main beam and start wandering around, it would not be in a region of no radar signals, but would immediately find some other crossover signal to suit its taste and follow it. Like as not it will be one of the adjacent elevation courses, particularly if the missile is in error in elevation only. For there are many of these courses that are not correct geographically but are correct electrically. The missile can very well follow out on one of these, while the radar itself is tracking the target on a different crossover, and completely pass up the enemy while apparently traveling on an intersecting path. Even this is not the end. For each course which has the correct sense, there exists one which is reversed. Should the bird find one of these in the elevation plane, it will be driven out of the beam in elevation, by climbing into the stalling angle or by diving out of it. If it should find its way into one of these in azimuth, it would drive out laterally, but be stable in elevation. The danger in this case is a real one as it will be impossible for it to return to the desired course and is likely to pick up one of these false courses at the time when it has turned around and headed toward the firing site. This possibility is not too remote, especially during the preguiding phase of its travel when it is groping for some signal on which to lock. The German experience along this line has been limited, but, after firing some 33 beam rider missiles, they found that the greater majority of them actually did this very thing, that is, turned around and headed directly into the guiding radar site with what was described as "obvious results".

Now going back to the case of vertical launching of missiles, it is likely that insurmountable difficulty will be experienced in attempting to make the "bird" lock onto the desired antenna lobe after the missile has been asked to execute the planned program, with the dispersions which exist at present. The main difficulty seems to be the fact that the missile is accelerated initially along its path by rather high impulse boosters, no two of which are exactly alike, and if several of them are used simultaneously, the resulting thrust is never exactly in line with the center of gravity of the missile-booster combination. The result is that, within rather large limits, it is impossible to know in just which direction the missile will travel. This dispersion is so great that the bird will often be completely out of the region of the main beam control at the time of the end of the booster acceleration. Even if only one rocket were used, the exact center of pressure of the jet would not be known in advance nor would it remain fixed throughout the burning time to sufficiently close limits to guarantee any better performance. The order of magnitude of this effect will be apparent when it is seen that a misalignment of the thrust line with the center of gravity of only one-sixty-fourth inch will result in the missile traveling a course several degrees different from that intended. This sort of accuracy is well beyond the realm of achievement in commercial production, and will therefore, remain an impassable barrier. The real difficulty is that this type of launching has utilized the principle of accelerating the "bird" in free space, that is, during a time which it was not guided by some mechanical means as a track or tube. This same criticism will apply to all methods using this principle, whether the bird is launched vertically or at any other angle. The difficulty may well be so serious that initial acceleration in free space may have to be abandoned for the short-range antiaircraft missile.

The other type of shipboard launcher under current consideration is known as the short rail launcher, or the "Zero Launcher". The same considerations discussed above will apply also to this. For the case where the missile is not fired vertically, some success has been achieved⁵ in reducing the initial launching dispersion by rapidly rolling the missile during the initial acceleration period thus delaying the operation of the roll stabilizing device until flying speed had been attained. If this method finally proves successful, as present figures indicate, it will indeed be a simple solution to an otherwise difficult situation. It will have the limitation when applied to vertical launching that it will be impossible to apply to the missile a turning trajectory during initial acceleration, a condition which may be a real handicap when engaged in close range warfare.

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If booster rockets are retained as a means of initial acceleration, it will be desirable to burn them faster than at present so as to impart a higher total thrust. The ultimate aim in this discussion is to obtain some sort of arrangement which will enable the missile to be constrained during the initial acceleration period so that the initial angular dispersion is eliminated and at the same time not to have a launching ramp too long to be accommodated on board a ship. Fifty feet is the length of the present launching catapult designed for shipboard use. Certainly this represents a maximum value, and if it could be reduced to 35 feet the difficulties would be greatly lessened. So far as the total booster fuel is concerned, it makes no difference how long it takes to accelerate a body to a fixed end speed if gravity and aerodynamic drag of the booster body are neglected. For the case of rather high accelerations these assumptions are justified. The table below shows the weight of booster fuel of specific impulse 150 lb-sec/lb necessary to accelerate 1000 lb of launching weight to various end velocities:

End Speed, ft/sec	Fuel Weight, lb
200	42
500	96
1000	185
1500	270
2000	344

If final end speed is to be attained by the time the missile reaches the end of the rails, the value of acceleration considerably higher than what is now in practice must be employed. The table below shows the relation of acceleration to the velocity achieved in a distance of 35 ft and 50 ft in terms of multiples of the acceleration of gravity.

Speed, ft/sec	G 35-ft ramp	G 50-ft ramp
500	111	78
1000	444	311
2000	1776	1243
3000	2514	1753

While it is desirable to have accelerations as large as this, there is not at present any complete missile which will withstand such treatment. The weak element, and for which no immediate solution is in prospect, is the gyroscope. To fire a piece of equipment at an acceleration of 2500 G with a gyroscope already run up and uncaged is a little outside the realm of immediate possibility. It might be possible to fire a dead wheel sufficiently well supported by some auxiliary structure and at the end of the period of high acceleration run the wheel up instantly before the reference axis is lost. An example of this requirement will be given. Let us take as an example, a wheel weighing two pounds and having a diameter of 3 inches. This has a moment of inertia of 0.1 slug-in². If it is desired to run this at 20,000 rpm it will have an angular momentum of about 200 slug radians in 2/sec. Let us allow 1/100 sec for the accelerating period, -that will correspond to an angular acceleration of 209,000 radians/sec². The necessary torque to accomplish this will be equal to 56,000 lb-ft. The only way this could be obtained would be through the use of an explosive charge discharging against turbine blades or grooves on the rim of the wheel. The total impulse force to be thus distributed around the periphery of the wheel would be 224,000 lbs. It is clear then that the difficulties are great no matter how the problem is approached. Any minute unbalance in the application of this tremendous force could easily damage bearings, bend shafts, or lock the wheel up against the supporting

pads. Compromises will have to be worked out at a number of points.

Something needs to be said concerning the time it takes to transfer information regarding a target from one place in the ship to another, and from one radar to another in particular. It has long been recognized that the length of this transition period is too great and is a critical item in the acquisition problem in the fire control field. With obsolete equipment, that is with equipment used during World War II, it took often as much as 45 seconds for a fire control radar to locate and begin to track a target which had previously been designated to it, and then often missed it altogether. Improvements are under development which will make the process faster and more automatic. While this is not the direct concern of the missile, yet it is of interest in that any undue delay in getting the "bird" into the air reduces the flexibility of fire. To make the matter clearer, there exists for each type of missile a definite time interval during which it is possible for it to be launched and still hit the target. This interval is being worked out for each condition of target speed and altitude for a non-evasive course. In a few cases the time spread is such that a delay of fifteen seconds might prove fatal. The only line of attack to this problem is the one of continually endeavoring to reduce all periods of information and / or control transfers to an absolute minimum. The delivering of as much information to the missile as possible before launching through the mediums of automatic computers and program presetters is a step in the right direction, and, as in the more conventional fire control field, will become an absolute necessity. In line with this philosophy is the idea that the missile must not be required to take valuable time in getting from the launching ramp into the main radar guiding beam. By firing it directly into a beam of zero parallax angle, all possible transition difficulties are reduced to a minimum. The shock of entering the beam is nil, necessitating the least amount of maneuvering before it is seriously on its way, and the danger of the missile choosing the wrong cross-over in the guiding beam is eliminated.

A study has been made² which has determined some preliminary theoretical figures as to the ultimate fire power necessary at a particular site to protect an area of fifteen square miles, against single airplane targets numbering not more than 1000 per hour or against raids of 100 planes in formation and encompassed within a square one mile on a side. The probability of kill was taken at 0.3 per "bird". With these and other conditions set up the resulting rate of fire was calculated to be 7 rounds per minute from each of 20 firing sites at the area, or a total of 8400 "birds" per hour for the dispersed attack and 7200 "birds" per hour for 100 plane formation attack with 1000 planes total per hour. If these figures can be taken as an indication for the order of magnitude of the necessary fire power of a fleet of ships it is obvious that every device within the reach of designers must be brought into play to reduce the auxiliary weight connected with initial boosting and the acceleration fuel to an absolute minimum in order to enable the storage of more missiles. Not the least of the worries will be that of having to carry thousands of these birds on board to be able to call them into play at a prodigious rate.

One method of projecting missiles which is receiving some thought is the method of launching by closed tubes. The savings to be effected in booster weight is about a hundred to one. Low pressure large bore guns can be used with either smooth or straight fluted barrels. Pressures in the neighborhood of 2000 lb/in² would suffice in many cases. A number of studies are underway, or completed, concerning this very attractive method of launching. To summarize the basic ideas to be kept in mind as the art of launching and guiding of missiles advances:

(1) Keep the pay load high.

This can be done by launching the missile to full flying speed without consuming the main propulsion fuel, by using the natural supply of oxygen in the ambient air to burn the fuel on board, and by distributing the explosive charge throughout the bird rather than concentrating it at the nose. This also lessens the

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danger to ground personnel due to the falling of large pieces of the "bird" after detonation.

- (2) Guide the missile mechanically throughout the entire initial acceleration period. This virtually eliminates the initial angular dispersion and helps the job of effecting beam capture.
- (3) Fire the missile directly into the beam without parallax. This requires the use of a launching device which is maneuverable in both azimuth and elevation, and a which is controlled automatically by the proper fire control computer.
- (4) Reduce the time required to prepare the "bird" for flight after being removed from magazine storage. This involves, if possible, the use of a nontoxic and noncorrosive fuel which might be placed in the bird at a considerable period before firing. It also pays attention to the possible storage in completely assembled condition. Firing failure due to corrosion while stored must be studied.
- (5) Reduce danger to operating personnel due to toxicity of fuels and accidental impacts of large booster bodies from high altitudes.
- (6) Reduce the weight of fuel necessary to initially accelerate missile to flying speed by the use of more efficient devices as closed tube or gun launchers.
- (7) Reduce the number of necessary radars to a minimum. This is accomplished automatically by item (3) above, and locate the antenna on the launching mount. The type of trajectory which demands a separate tracking and guiding radar offers advantages which are problematic and of academic interest only in those cases where the missile speed is at least twice as fast as the target.
- (8) Maintain a vigorous personnel training program.

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APPENDIX 4

Guided Missile
Shipboard Launching Problems

by

Commander J. H. McQuilkin

In a recent conference, a spokesman for one of the missile development agencies discussing the progress of his group likened it to the landing of a large expeditionary force on the shores of a jungle-infested land. He stated that a considerable amount of men and material had been landed and that unloading was still continuing; that reconnaissance parties had struck inland and that some skirmishing was in progress. However, the battle had barely begun. If this be true, then to continue the analogy, the ship designer is in the status of just recruiting an expeditionary force but has not been told what continent he is to attack or even what ocean he will have to traverse to get to it.

To date, those of us in the ship design business have been acting mainly in the role of observers in the guided missiles field - getting underfoot at times, asking exasperating questions at others, but, we hope, absorbing sufficient information to give us a background for the future. We have been, and are greatly handicapped by lack of specific information concerning the characteristics of missiles in general, and information concerning those missiles which are being developed, or can be adapted to shipboard installations.

If you have been reading the newspaper and such magazines as Popular Science, not to mention the London Illustrated News, you must know that the Navy is contemplating completion of the USS HAWAII (CB3) as a Guided Missiles Ship. The characteristics of this vessel furnished by the Chief of Naval Operations contain such neatly phrased requirements as - "the ship shall have three major caliber missile launchers for so many major caliber missiles". When the designer tries to fit such characteristics into a hull of finite dimensions, he finds himself almost blocked at the first turn.

Nevertheless, we have been making a number of studies in which we have uncovered a number of the problems which will ultimately confront us. We by no means profess to have solutions to all, or even many, of these problems and we are certain that there are many, many more which are yet to be uncovered. In many of these problems, the answer must of necessity await the advent of the missile concerned.

The solution of these problems must be, in some respects, a joint effort on the part of the missile development agencies and the ship designers. In this, we do not wish to lay down any restrictions whatsoever nor even arbitrary rules: however, as the development of missiles passes from the component study stage into the hardware stage, I think that it would be well if some of the shipboard problems were at least known to the missile designers.

Before we can discuss specific shipboard problems, the first big question to answer is what kind of a ship to start off with. Budgetary restrictions, being what they are, make it practically certain that our first efforts along these lines must be in the form of conversions rather than new construction. The USS HAWAII falls within this category. In the majority of respects, this is a marked disadvantage but it does allow us to feel our way into this new field with some measure of economy.

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I. Choice of Ship

A. Type of missile to be employed

1. This may determine ship by virtue of physical reasons alone.
2. Will determine other characteristics of ship such as speed, cruising radius, command facilities, etc.

B. Size of Missile

1. Naturally affected by type.
2. Size of ship will go up in proportion to size of missile.
3. As size of missile increases, so will attendant problems.
4. As size of missile increases, roll period of ship enters picture.
5. So does superstructure height for supporting, etc.

C. Conclusions

1. With missiles as now being developed, ship of cruiser size appears minimum feasible. British concur in this.
2. Danger in developing other thoughts on this - amphibious types.
3. Types such as BB-CB-CV - all acceptable.
4. Smaller ships must await much smaller missiles -. Note problem of fitting Weapon "A" on DD.

II. Ship Arrangement

A. Launching Devices

1. Number
 2. Size
 3. Type
-) Affects arc of fire available.

B. Rate of Fire

1. Requires a compromise between number of launching devices and arrangement of delivering missiles to such devices.
2. Will probably go up.
3. Any assembly or fueling operations will be detrimental to high rates of fire.

C. Control Equipment

1. Number - one per launching device?
2. Size.

D. Other Equipment

1. Conventional gun battery - period of transition inevitable.
2. Stacks.
3. Search radar - large antenna such as XDQ.
4. Masts, etc.

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E. Blast Effect

1. Considerable problem now with guns.
 - a. On structure
 - b. On personnel

F. New Construction vs. Conversions

1. Conversions must be made - hence we are restricted to a hull based on conventional gun positions. Two forward-one aft.
2. Construction of new designs can be functional.

III. Launching Devices

A. Ramps

1. Length.

B. Catapults

1. Length XM2 - 50 ft.
2. Elevation.
3. Train - horn locking.

C. Guns

1. Similar to present ships.

D. Launchers

1. Length.

E. Stabilization

1. Complexity of large number of individually stabilized mounts as well as weight involved.
2. Possibility of stabilizing entire ship.
3. Is stabilization necessary?

IV. Handling

A. Fragility of missile

1. Movement of ship will increase problems involved in handling.
2. If so fragile that performance is liable to suffer due to knocks, elaborate precautions must be taken.
3. Missile may require special support points.

B. Size of missile

1. As size goes up, power handling becomes mandatory.

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C. Developments required

1. Hoists - 1 year now needed for ammunition hoists.
2. Cranes.
3. Erection devices, etc.
4. Weapon "A" analogy.

V. Fuels and Fueling

A. Types of Fuels

1. Semi-safe.
 - a. Kerosene
 - b. Alcohol
 - c. Gasoline
2. Dangerous.
 - a. Acids
 - b. H_2O_2
 - c. Etc.
3. British restrictions.
4. Our investigations.
 - a. No restrictions at present
 - b. Effect of hot fragments, etc.

B. Fueling

1. Fuel stowed in missile.
 - a. Corrosion of missile itself
 - b. Danger of stowing fuels (different) in close proximity
 - c. Length of time in dead stowage permitted
 - (1) Arrangement of magazines
2. Fuel stowage in bulk.
 - a. Tanks, pumps, piping, etc.
 - b. Amounts, pressures, etc.
 - c. Rates of delivery
 - d. Delivery points
 - (1) Assembly line
 - (2) Launching points
 - e. Danger to ship
3. Fuel stowage in packages.
 - a. Canned fuel

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VI. Stowage

- A. Fuels - as above
- B. Warheads
 - 1. In magazines below W.L.
 - 2. Where and when - and how - attach to missile.
- C. Body Breakdown
 - 1. To fit areas available.
- D. Boosters
 - 1. Detachable fins.
 - 2. Where attach to missile.
- E. Ready Service
- F. Structural limitations
 - 1. Deck heights.
 - 2. Transverse subdivision.
 - 3. Strength of ship - large hatches, etc.
 - 4. Accessibility for checks of electronic equipment, etc.
- G. Control of Moisture
 - 1. Salt air corrosion.
 - 2. D/H or strippable film.
- H. Vibration

Conclusion:

I have attempted, in a brief way, to cover the problems of the shipboard launching of G/M as we now visualize them. As you can see, there are many problems. A very few are already solved, others are nearing solution - but the great majority must remain unanswered until the variables are more fully delineated. We realize that the solutions to your problems must be obtained before we can start attacking many of ours. I appreciate the opportunity of presenting to you some of our troubles - maybe it'll make yours seem just a bit lighter.

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VI. Shows

A. Vials - as above

B. Wafers

- 1. In magazines below W.L.
- 2. Where and when - and how - attach to missile

C. Body Breakdown

- 1. To fit mass available

D. Boosters

- 1. Detachable fin.
- 2. Where attach to missile

E. Ready Service

F. Structural Limitations

- 1. Deck height
- 2. Transverse subdivision
- 3. Strength of ship - large hatch, etc.
- 4. Accessibility for checks of electronic equipment, etc.

G. Control of Moisture

- 1. Salt air corrosion
- 2. D/R or stripable film

H. Vibration

Conclusion

I have attempted, in a brief way, to cover the problems of the shipboard launching of G/M as we now visualize them. As you can see, there are many problems. A very few are already solved, others are nearing solution - but the great majority must remain unanswered until the variables are more fully defined. We realize that the solution to your problems must be obtained before we can start attacking many of ours. I appreciate the opportunity of presenting to you some of our troubles - maybe it'll make your's seem just a bit lighter.

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