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RECOMMENDED RESEARCH PROGRAM FOR DEVELOPEMENT OF MID-COURSE GUIDANCE SYSTEM FOR LARK

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RECOMMENDED RESEARCH PROGRAM FOR DEVELOPEMENT OF MID-COURSE GUIDANCE SYSTEM FOR LARK

by

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April 1947

Approved by:

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ABSTRACT

A research program, directed toward the development of a beam-rider guidance system for the Lark missile, is described. An outline of the proposed investigations, mathematical studies, research and development work to be accomplished by the Naval Research Laboratory, is given. A technique to predict performance of a guidance system, envisioned as a closed loop servo, including the airframe response is developed. A method to develop correlation between predicted performance and observed performance of the guidance system is defined using an airplane as a controlled test vehicle. A research program, directed toward the prediction of the performance of a guidance system in the Lark missile and establishing a means to correlate predicted performance with observed performance, is recommended.

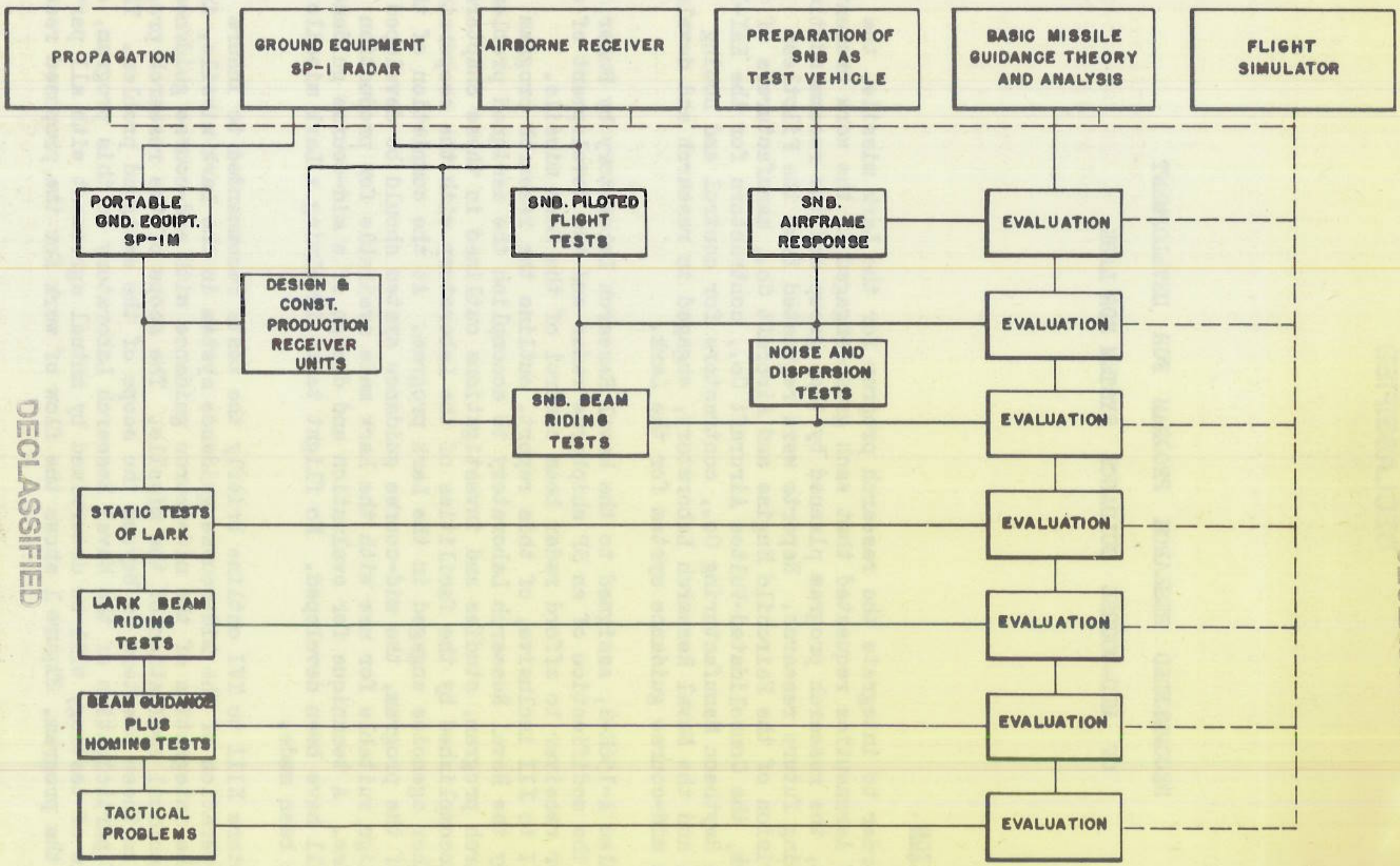
RECOMMENDED RESEARCH PROGRAM FOR DEVELOPMENT OF MID-COURSE GUIDANCE SYSTEM FOR LARK

INTRODUCTION

In order to integrate the research program for the Lark missile, the Bureau of Aeronautics requested that each group engaged in the work present, by report, the research program planned by that group and the recommendations for planning future research. Reports were requested from the Pilotless Plane Division of the Fairchild Engine and Aircraft Co., manufacturers of the KAQ-1 Lark, the Consolidated-Vultee Aircraft Co., contractors for the KAY-1 Lark, the Raytheon Manufacturing Co., contractors for control and homing equipment and the Naval Research Laboratory, engaged in research and development of a mid-course guidance system for the Lark.

Problem A-156R-S, assigned to the Naval Research Laboratory by BuAer, requests the modification of an SP shipborne radar and the development of a beam-rider receiver to afford radar beam control of the Lark missile. Chapters I to XII inclusive, of this report, outline the research program planned by the Naval Research Laboratory to accomplish the assigned problem. The research program, studies and investigations outlined in these chapters will be accomplished by the facilities of the Laboratory with the cooperation of the other agencies engaged in the Lark program. At the completion of this portion of the program, the mid-course guidance system should be developed and a design suitable for use with the Lark made available for production manufacture. A technique for evaluation and design of a mid-course guidance system will have been developed. No flight tests involving a Lark missile will have been made.

Chapters XIII to XVI outline briefly the tests recommended to insure correct operation of the mid-course guidance system in the Lark missile, including the integration of the mid-course guidance with end-course guidance and the tactical evaluation of the missile. The scope of the research program involved in these chapters is beyond the scope of the assigned problem. The degree of participation of the Naval Research Laboratory in this program, at the locale of testing, will be determined by mutual agreement with all participants of the program. Figure 1 shows the flow of work for the proposed research program.



—TEST PROGRAM FLOW CHART—

FIGURE—I

CHAPTER I

PROPAGATION

A. MULTIPLE CONTROL PATH STUDIES AND TESTS

The purpose of these studies is to investigate the existence and effect of multiple control paths, or false crossovers, of the radar beam, caused by reflection of the radar beam from the ground and side lobes of the radar beam.

The missile cannot distinguish between a false crossover and the crossover of the radar beam itself. Preliminary study indicates that the existence of multiple control paths at extremely low elevation angles may mitigate against the tactical usefulness of the beam riding guidance system under these conditions.

These studies were made by Mr. W. F. Ament of Radio Division I, Naval Research Laboratory. The results of the initial study were presented at the Lark-Wasp Seminar of 17 October 1946 by Mr. Ament. A Naval Research Laboratory report No. R-3071, detailing the investigation, will be issued in the immediate future.

It was mathematically determined that there will exist false crossovers or false control lines caused by reflection and by side lobes. As an example of the magnitude of this problem, considering the SP Radar used for control of the Lark - at a two degree elevation angle there are approximately forty-one reflected crossovers. This elevation angle is the equivalent of tracking a target at 1100 ft. altitude at 10,000 yards. This statement does not consider the effect of side lobes which unduly complicates the mathematics of the study. The number of false crossovers is dependent upon the elevation angle of the antenna and the beam characteristics of the radar. With the SP antenna pattern above four degrees elevation angle, the effect of false crossovers caused by reflection will disappear.

Each alternate crossover is unstable in that it imparts to the missile the wrong sense of direction. This is also true of alternate false crossovers caused by side lobes.

There are other parameters of this problem still to be investigated. The reflected beams will cause signal nulls on the true control line. An investigation of the frequency of interception of null points in flight as against elevation angle and range may be necessary to determine if the existence of these nulls will impart false information to the missile.

CORRELATING TESTS

Correlating flight tests to determine the existence, the sense, the magnitude and the effect of false control lines caused by reflection and side lobes will be made. An investigation will be made of the existence of nulls in the true control line caused by reflection and the probable frequency of such nulls will be considered for the Lark missile. These tests will be conducted by personnel of Radio Division III, NRL. It is estimated that correlating evidence of this mathematical study can be completed by August 1947. It is not anticipated that any special instrumentation will be required for these tests.

While no definite conclusion may be reached at this time, available information indicates that capture and control of the missile may be difficult at low elevation angles, if not tactically impossible.

B. FLAME ATTENUATION TESTS

Measurements of flame attenuation and modulation of that attenuation have been and are being made to determine the nature and extent of jet flame interference with the propagation of S-Band electromagnetic waves. Flame attenuation tests were made by the personnel of the Components Section of Radio Division III of NRL. The initial exploratory measurements with a static motor were made at the Reaction Motors Inc., Dover, N.J., in March 1947.

Radio Division III and the Optics Division of the Naval Research Laboratory furnished personnel and instrumentation; the Reaction Motors Inc. furnished test facilities. Approximately seven men constituted the field party for these tests.

Analysis of data will be accomplished by the Components Section, Radio Division III. No special facilities for this analysis are indicated at the present time. Results of these tests will be discussed at the Lark-Wasp Guided Missile Seminars and presented in a Naval Research Laboratory formal report.

These tests are to be considered preliminary exploratory tests only. It is anticipated that further extensive studies will be necessary. No definite plans will be made for flight tests until the completion of the analysis of the data from these preliminary investigations and the determination of how much further it will be necessary to pursue these measurements.

C. OPTIMUM CROSSOVER STUDIES

The determination of the optimum crossover for a conically scanned radar designed both for tracking a target and guiding a beam riding missile, simultaneously, involves the consideration of several incompatible parameters. To obtain the maximum reliable range of the radar, it is desired to have as small a scanning angle as possible; for accurate linear tracking, a wider scan angle is needed to obtain precise measurement of target angle and its derivatives; and, since the beam riding missile follows only the one way antenna patterns, a still wider scanning angle is desirable to obtain the highest modulation sensitivity; conversely, to achieve greatest reliable range for the missile, it is desirable to have a small scan angle. In order to arrive at a reasonably accurate idea of these various parameters, a study was initiated to determine the relationship between them and to determine optimum crossover or optimum scan angle for a radar which was both tracking a target and simultaneously guiding a missile.

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The study was made by the Consultants Group of Radio Division III, NRL. This study was mathematical in nature.

The preliminary results of this study were reported in a paper entitled, "Optimum Beam Crossover for Guiding and Tracking SP Radar", by Mr. C. L. Key, of Radio Division III. This paper was presented at the Lark-Wasp Guided Missile Seminar, February 1947.

This study indicates that if all parameters are weighted equally the scanning angle which gives the most nearly optimum results in all parameters should be so adjusted as to be approximately 1.8 db down at crossover for a two-way pattern. It should be pointed out, that for the purpose this SP will be used, it may be desirable to sacrifice range in order to gain better target tracking or more effective guidance of the missile.

CORRELATING TESTS

Following the modification of the antenna feeds in the SP-1M radar, correlating tests will be made. One-way and two-way antenna patterns will be obtained and reliable ranges will be determined. With this information, an investigation will be made to determine the adjustment, if any, which will be required to obtain optimum tracking and guiding by this radar. If adjustments are required, continued tests will be made following these adjustments.

These tests will be made by the personnel in the Beam Ways Section, Radio Division III. No special instrumentation or additional personnel will be required. It is estimated that these tests will be completed in April 1947. Analyzing of data obtained and evaluation of the same will be made by the Beam Ways Section, Radio Division III.

D. NOISE - STUDIES AND TESTS

The studies on noise have been directed toward the effect of noise on the closed loop response of the guided missile; determination of error in the missile path caused by noise; information to lead to the design and choice of bandwidth to eliminate the effects of noise; and toward the investigation of secondary effects (such as estimates of servo power storage required, since noise will be the predominant factor in the dissipation of this power). Noise, as defined for the purpose of these studies, does not include such interferences may be caused by the jet, but rather the signals which may be caused by mechanical irregularity in scanning, irregularity of pulse time, irregularity of pulsed power, interference in the dielectric medium, static and inherent receiver noise.

Dr. L. R. Philpott of the Consultants Group, Radio Division III, Naval Research Laboratory, presented a paper at the Lark-Wasp Seminar 7 November 1946 entitled, "Effect of Noise on Wasp Type Control Missiles".

Mr. W. F. Ament of Radio Division I, NRL, has been engaged in a study of noise on the basis of analog comparison with random AC voltages in a resistor. The problem of finding the instantaneous voltage in the resistor and the problem of finding the instantaneous position of an erractically wandering missile are analogous. This study will be continued.

E. NOISE TESTS DECLASSIFIED

The purpose of these tests are to measure the noise output from the receiver; to determine magnitude and character of the noise during flight; to evaluate therefrom the effects of noise on Wasp guided flight; and to correlate the measured data with mathematical studies.

These tests will be made by personnel of the Equipment Research Section, Radio Division III, at Fort Drum, following initial receiver flight tests. The tests are described fully in Chapter X.

F. RECEIVER ANTENNA STUDIES AND DESIGN

The specification for the Lark receiver antenna, Problem A-156R-S, states: "Beamwidth not to exceed thirty degrees, with maximum front to back ratio". An antenna was designed, polarized for mounting on a vertical wing. Information was obtained from one of the airframe contractors to determine the necessary shape and size of the antenna to conform to the wing form. An antenna has been constructed. The design has been submitted to both airframe contractors for comments and possible modifications.

This work to date has been accomplished under the direction of Dr. L. C. VanAtta, of Radio Division I, Naval Research Laboratory.

An investigation is underway to determine the feasibility of and circuitry required for a dual antenna system, if the attenuation test previously described dictate the use of two antennas to secure optimum geometry for avoidance of flame effects. It is estimated that the study can be completed within two months following the conclusion of attenuation tests.

G. BEACONS FOR LARK

For test purposes, it will be necessary to track the Lark in flight. Examination of the bird, from the point of view of radar reflection, indicates that this will be an exceedingly difficult problem. Preliminary estimates indicate that the equivalent reflection area of the Lark is 0.07 sq. meters from rear aspect. Comparable reflecting areas are: the Baka bomb about .10 sq. meters; the SNB about 10 sq. meters. A detailed examination of the range to which the SP Radar can track the Lark is now underway, but even superficially, it can be seen that it will be necessary to equip the Lark with a beacon if it is to be observed beyond a few thousand yards.

The use of a beacon is for test purposes only; it is not desired to complicate the production design of the missile receiver by utilizing the receiver video pulse or blanking off the receiver during the time of the beacon's response. For this reason, the beacon will be forced to transmit on a different S-Band frequency than the SP-1M Radar. Additional receiver circuits in the SP-1M Radar may be required. The changes to the SP-1M receiver circuits to include the use of a beacon are under study by the Beam Ways Section of Radio Division III.

The beacon requirements, for test use, are stringent. It is desired to obtain measurements of the position of the bird to within ±10 yards in

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range. A study of beacon requirements is underway by the Command and Report Links Section of Radio Division III.

AVAILABILITY OF BEACON EQUIPMENT

Preliminary investigation of S-Band beacons indicates that none are available that will satisfy the accuracy criteria desired for test purposes. An investigation is underway by the Command and Report Links Section of Radio Division III, as to the time required to develop and produce a satisfactory beacon.

Two antennas will be required, the receiving antenna can be the same antenna that is used by the Lark beam guiding receiver by matching the impedances of both receivers; the transmitting antenna will be a similar antenna installed on another wing tip. Available space in the bird is a matter of prime importance.

CHAPTER II

GROUND EQUIPMENT

Problem A-156R-S specifies that the primary purpose of this project is to "modify the SP shipborne radar and with a radar beam control receiver effect control of the Lark missile". With this as a basic concept, the following specifications for modification of the SP radar are given:

a) The operating range for missile guidance shall be at least 90,000 yards.
b) The target dimensions shall be comparable to a medium bomber in a head-on course and position.
c) The SP shipborne radar shall be capable of having pulse repetition frequency varied in such a manner as to transmit the necessary proportional control intelligence to the radar beam control receiver in the missile.
d) The equipment shall be modified to incorporate automatic tracking in elevation and in bearing which shall be positive in action. Such automatic tracking shall be capable of, when once set on the target, following the target without losing it.
e) The frequency shall be in the S_y band (2600 to 2700 mc) adjacent to the shipborne SP frequency.

There are other modifications not anticipated at the time of issuance of the above specifications, which may be required for optimum operation of the SP radar as ground equipment for the Lark. These possible modifications are:

a) Modification of the antenna feed. The General Electric Company, manufacturers of the SP radar, have recommended the installation of a modified antenna feed and scanning arrangement as a field change. The modification is expected to increase the range and to decrease the effect of side lobes. This modification has been applied to the SP-1 radar and new antenna patterns will be obtained in April 1947 by tests made by the Beam Ways Section of Radio Division III.
b) Beam Crossover. A preliminary investigation of the optimum beam crossover for both automatically tracking the target and guiding a missile, has been made by the Consultants Group of Radio Division III. It has been indicated by this study that optimum performance may be expected with the crossover about 1.8 db down. In order to obtain the desired modulation of the signal at the missile receiver for a given error, it is believed that it will probably be necessary to modify the antenna feed. This statement cannot be made with assurance until a determination of the modified antenna patterns has been made.
c) Automatic Range Tracking. For tactical operation of the Lark, it will be necessary to track only the target. The specifications of the problem do not include automatic range tracking. It is believed that automatic tracking in this coordinate is essential to optimum operation of the Lark control system. For test purposes,

it will be necessary to track the missile and record information as to its bearing, elevation and range within extremely close tolerances for error. The range circuits of the SP are being modified on the following basis: maximum range rate 350 yds per second; acceleration 100 yds per second sq; accuracy, by use of crystal calibration, it is believed that the range can be measured to plus or minus 10 yards. For fleet use without calibration, the accuracy of the range unit will be plus or minus 25 yards. Slew speed to be 10,000 yds per second with dynamic braking. Type 5G synchros will be used for range and range rate transmission at 1,000 yards per revolution and 100,000 yds per revolution. Potentiometers for altitude computation will be retained.

The spark gap modulation of the SP has been replaced by a hydrogen thyratron frequency modulation system. A new automatic gain control system has been completed. Tests showed good response through about seven cycles per second and effective rejection filtering of the 24 cycles per second scan rate. The automatic tracking circuits are completely designed. Installation of the antenna drive servos are in progress.

It was found necessary to completely examine the mount proper with a view to reducing the frictional load. This has been accomplished by mechanical reworking. The mount was seriously unbalanced around the train axis; this has been corrected by the application of counter-balancing material.

Upon completion of the mechanical reworking of the servos and the automatic tracking circuits, the frequency response of the mount servos will be extended by at least one octave. This will result in a very material gain in the characteristics of tracking for the SP mount. The improvement to this mount has been handicapped by the inherent and undue frictional loading and the characteristics of components utilized in the mount servos. Upon completion of the modifications, the mount will be fully satisfactory for any work in tracking it may be called upon to do in the course of the Lark missile use.

CHAPTER III

AIRBORNE EQUIPMENT

BuAer problem A-156R-S covers two items of airborne equipment: the receiver and the antenna. The antenna has already been discussed under Propagation Studies. The airborne receiver, designated as AN/APW-4, has been the subject of many studies and tests. The design considerations have included utilizing missing pulse and quadrant type receivers for purposes of obtaining reference. Such systems are merely variations of the basic use of pulse time modulation for obtaining the reference vertical. By sinusoidally modulating the pulse repetition rate throughout the entire scanning cycle, the reference information is continuously generated. There are no fundamental problems involved in modulating the pulse repetition rate over the entire scanning cycle that are not equally involved in other systems. Other types of reference systems have been considered. The character of the receiver has undergone considerable investigation; crystal video receivers have been tested and found unsatisfactory because of excessive harmonics and microphonics. A receiver of the superheterodyne type has been flight tested with partial success. A new receiver, designed to eliminate the faults uncovered by these flight tests, is nearing completion.

The function of a receiver is to obtain intelligence from the ground radar and to interpret the intelligence in such a manner as to produce signals which can be used to maintain the missile always on the radar line-of-sight. Intelligence is transmitted by two means, - amplitude modulation and frequency modulation. Amplitude modulation is used to determine the distance of departure of the missile from the radar line-of-sight; pulse time modulation is utilized to create a reference from which the direction of the departure of the missile from the radar line-of-sight is obtained.

The SP radar is conically scanned at 24 cycles per second; it is pulsed 24 times each scanning cycle. When the receiver is on the radar line-of-sight, the received strength of each pulse will theoretically be the same; when the receiver is not on the radar line-of-sight, the received strength of each successive pulse will differ. This constitutes amplitude modulation; the difference between the maximum and the minimum received signal strength is a measure of the value of error between the line-of-sight and the location of the receiver.

When the gain in the receiver is constant for all ranges between the receiver and the radar, the error as measured by amplitude modulation is a function of angular displacement from the radar line-of-sight. When the gain of the receiver is increased proportionally with range, amplitude modulation may be used to obtain a linear measure of error.

The time interval between pulses of the transmitting radar is varied sinusoidally to furnish frequency modulation as a reference to indicate direction of the error. The reference modulation, received in polar coordinate form, is transformed within the receiver to equivalent sine and cosine function. The resolved X and Y coordinates of the error are determined by multiplying the value of the amplitude modulation by the cosine and sine reference signals.

Ground tests of the latest design of receiver are now under way, using the SP-1M radar which has been recently relocated within the Laboratory grounds. The ground tests will determine the value of the amplitude modulation as a function of error for various gain settings of the receiver. The frequency response of the receiver will be checked against the predetermined response characteristic.

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CHAPTER IV

PREPARATION OF SNB AS TEST VEHICLE

In fully investigating all of the problems of developing a beam riding guidance system, it was decided, as a basic policy, that the initial phases of the development would be based on what was already known; and each step carefully investigated in all parameters before taking succeeding steps into unknown fields. In order to fully examine all parameters of receiver design in flight and problems of propagation, an SNB type airplane has been and will continue to be, utilized as a flight test vehicle.

PHOTOGRAPHIC TEST

It has been the experience of the Operational Research Section, which has conducted inumerable tests of tracking radars and fire control systems, that in coastal areas haze and water content in the atmosphere limits the photographic recording of plane flight to about 16,000 yds under optimum weather conditions. The specifications call for Lark beam riding guidance system to be operative to a range of 90,000 yards. A series of tests has been made to determine the maximum photographic range, using the SNB airplane.

A 500-watt landing light was mounted on the under side of the plane facing aft. Tests have been made on the use of various film emulsions (infra-red, Super X, shell burst, and color). The films were tested using varied shutter speeds, lens orifice openings and telephoto lenses. The best results were obtained with color film and a minimal exposure and a 17" telephoto lens. Satisfactory recording of plane position was obtained at 54,000 yards on a moderately clear day. Tests were made on the use of other light sources, one of which was a zirconium oxide high intensity light, but the 500-watt landing light was found to be the most satisfactory.

AUTOPILOT INSTALLATION

A study was made of the suitability of existing autopilots. As a result of this study, it was decided to use P-1 autopilot manufactured by Bendix Aviation Corporation, Teeterboro, New Jersey. SNB No. 39970 was flown to Teeterboro and a P-1 autopilot, modified to the extent that oversized servo drives were used, was installed by the Atlantic Aviation Corporation under supervision of Bendix engineers.

MODIFICATION OF P-1 AUTOPILOT

Simultaneously with the installation of an autopilot in the SNB, a second P-1 autopilot was modified at NRL to accept signals from the airborne beam riding receiver.

The autopilot obtains stability in the horizontal plane by use of a rate gyro. When flying a straight course, the output from this gyro, the turn gyro, is zero. Deviation from a straight flight course in the horizontal plane, will cause the gyro to produce an electrical output proportional to

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the rate of turn from the straight course. Turns are coordinated by feeding inputs of correct proportion to the rudder, elevator, and aileron servos. The plane will continue to turn at the proper magnitude until the turn controller is returned to zero position, at which time straight flight will be resumed. Stability in pitch is maintained by using the output of a vertical free gyro to control the movement of the elevator, and consequently of the airplane. Any divergence between the relative position of the vertical gyro and the airplane results in a signal with proper polarity to reduce the error in the flight path.

The autopilot was modified by adding a servo drive to the turn controller. (The turn servo contains proper equalization so that the airframe is stable in flight when following the control line established by the radar). In pitch a differential generator has been added to the system between the synchro receiver of the vertical gyro and the pitch control servo system. The differential generator is driven by a servo drive which contains proper equalization so that the airframe is stable in flight when following the radar control line.

Separated X and Y coordinate error signals from the receiver output are fed into the two servos, one of which operates the turn controller, the other of which operates the pitch control. In this manner, intelligence picked up by the receiver controls the SNB airplane.

INSTALLATION OF MODIFIED AUTOPILOT

After the components of a P-1 autopilot were modified as described in the preceding paragraph, they were thoroughly bench tested to check interaction of all components. The frequency response of all components of the autopilot were determined and compared with the design specifications as set up for the closed loop system from the frequency spectrum analysis of the missile trajectories.

Following the bench tests, the modified components were installed in the airplane, replacing the standard components already installed. The action of the modified components has been tested in the plane on the ground. Frequency response measurements of the system has been made on the ground by applying constant amplitude variable frequency input signals to the turn and pitch control servos, and measuring the amplitude of output of the rudder, elevators, and ailerons. Adjustments have been made to properly coordinate banking and turns to maintain constant altitude during manuevers of the plane.

The autopilot modifications did not destroy the usefulness of the device for ordinary flight purposes.

FREQUENCY RESPONSE TESTS OF AIRFRAME, SERVOS, AND MODIFIED AUTOPILOT

The use of frequency response analysis techniques and the conception of the airframe and autopilot as components of a closed loop servo representing the overall guidance system has been thoroughly discussed at Lark seminars, both by presentation of papers and in oral discussions. After determination of the response characteristics of the autopilot components and the servos on the ground as discussed in the preceding paragraphs, flight tests will be made to compare the response characteristics of the combination of these components and the airframe with the design specifications. See Chapter VII for details of the flight tests.

CHAPTER V

BASIC MISSILE GUIDANCE THEORY AND ANALYSIS

In the course of the development of a guidance system, it becomes necessary to examine parameters of basic problems beyond the realm of the assignment. Such problems require a miscellany of knowledge and skills and necessitate continued studies and investigations as the details of the problem itself become outlined. It is necessary to carry on supporting developments of alternate systems so that no detail may be overlooked and to insure ultimate success in the development of a guidance system.

PRELIMINARY INVESTIGATION - STUDY OF AVAILABLE COMPONENTS

When the problem of providing a guidance system for the Lark was initially proposed (during World War II), a study of available radars was made to determine the most suitable radar for use for the problem. The radars examined included the fire control radars then available, search radars, and the SCR-584 of the Army. The studies included the characteristics of the radars; the ease of modifying them by field change; the presence of radars in the Fleet; and the existence of personnel trained and qualified to operate and maintain such radars. On the basis of these studies, it was recommended that the SP radar be adapted for use with the Lark.

Similar investigations were made to determine the type of airplane to be used as a test vehicle. On the basis of these studies, it was recommended that an SNB be utilized for test purposes.

An investigation of available autopilots was made. From this investigation the P-1 autopilot was selected and has been modified and tested for use with the test flown receiver.

Many such studies and tests have been required and will continue to be required as this development work proceeds. The studies are based on practical considerations of the components which are presently available and which are suitable for modification for the requirements of the guidance system.

TRAJECTORIES AND TRAJECTORY DYNAMICS

There have been many studies of trajectory dynamics made by the Naval Research Laboratory, both in connection with the Lark problem specifically and the guided missile problem generally.

Trajectory studies specifically directed toward the Lark problem are two-fold; investigation of the frequency spectra of the Wasp controlled missile trajectory and an examination of Lark trajectories to determine the usefulness of the Lark as a test vehicle or a tactical weapon.

TACTICAL PROBLEM vs. TRANSMISSION BANDWIDTH

The trajectory of a beam riding missile to combat a target flying a known course may be established. The missile trajectory may be transformed into a frequency spectrum associated with the required turning rates of the missile. With the frequency spectrum of the missile known, the bandwidth of the servo system controlling the missile may be adjusted to pass sufficient intelligence so that the missile tracks with a tolerable error, yet eliminates or attenuates extraneous modulation caused by noise, ground reflection, flame attenuation, etc., which otherwise may cause the missile to follow an erratic course.

The turning rate frequency spectra for the following courses were investigated: straight line approach course, circular course, and straight line pass course.

It is believed that this technique of investigating the dynamics of missile trajectories is significant. It permits determination of the maximum bandwidth required by the servos to transmit the guiding intelligence for a given tactical course to the exclusion of extraneous signals. Knowledge of the frequency transmission characteristics of the missile controlled as a closed loop system makes it possible to operate upon the frequency spectra of the missile for any given tactical course, thereby to predict the probable errors of the missile guidance system. This information may be used to determine the location of the missile with respect to the beam center at the time of transition from mid-course to end-course guidance.

The studies have been made by the Equipment Research Section of Radio Division III and are being continued in an effort to explore various tactical courses. Report R-2930 entitled, "Study of Frequency Spectrum Associated with Idealized Beam Rider Missile", issued on this study as significant progress is achieved.

<u>TACTICAL LIMITATION OF THE LARK AS DETERMINED BY TRAJECTORY ANALYSIS</u>

By examination of the trajectories of the Lark against various tactical target courses, it is possible to determine, by graphic solutions, the limitations of the Lark as a tactical weapon or as a test device. The majority of the limitations are practical parameters. For example, the length of time the Lark may be maintained in powered flight is determined by the amount of fuel carried by the bird and by the trajectory which is imposed upon it. It is obvious that if the Lark were fired too soon, it might easily run out of fuel before a collision point between the target and the Lark has been reached. Similarly, because of the fact that the roll stabilizing free gyro in the Lark will tumble at approximately sixty degrees elevation angle, the trajectory of the Lark cannot be predicted when the bird exceeds that elevation angle. The initial graphical studies will be used to outline a series of required trajectory analyses which, by the very nature of their complexity, must be developed by use of computers or simulators.

This study is being conducted by the Consultants Group of Radio Division III. A program of studies will be forthcoming to be used with the computer now under manufacture by the Reeves Instrument Company. It would seem inevitable that the studies will indicate the necessity for additional aerodynamic information at present unforeseen. The results of these studies will be discussed at Lark-Wasp seminars, when the significance of the study becomes apparent, or as additional information from the airframe manufacturers becomes necessary. Such studies will also be reported fully in formal reports.

INVESTIGATION OF TRANSITIONAL GUIDING PERIODS

There are three transitional guidance periods which, while not a part of the mid-course guidance problem, are vitally important to the effective use of any form of guidance system. A detailed examination of the conditions existing during these periods is vital to the success of the bird as a tactical weapon or a test device. Detailed considerations are not possible at this time because so little is known of the behavior of the bird during these periods. For that reason, investigations now under way at the Naval Research Laboratory are general in character, and at present form merely a basis for continued investigation. The three phases are: launching, capture, and transition from beam riding to homing guidance. The preliminary investigations at the Naval Research Laboratory have been made by Dr. L. R. Philpott of the Consultants Group, Radio Division III.

The transitional periods have been discussed verbally during the Wasp-Lark seminars. Reports have been made of the preliminary investigations. Formal reports on the preliminary studies and further investigations will be issued as the occasion warrants. Continued investigation of all phases of the problems presented is considered essential to the ultimate success of the Lark program.

The Bureau of Aeronautics has assigned to the airframe contractors the problem of developing suitable launching means for tactical and test purposes. On the basis of the designs and studies of the contractors, there will be determined the practical launching dispersions of the missile. The accuracy of the missile controlled by preset, programmed flight before capture by the radar beam will be fully explored by the contractors. Studies to determine the limiting parameters of capture at various ranges from the radar are now under way by the Consultants Group of Radio Division III. On the basis of these studies, it will be possible to work backward and determine the limiting dispersion from the launching device. With this information in hand, the design characteristics of the launcher as developed by the airframe contractors may be examined to determine if successful capture of the missile is possible.

If the investigations of the airframe contractors and the Naval Research Laboratory indicate that the control, for the transitional period between launching and beam riding capture, must be preset or programmed, it may be necessary to develop a computer and programming device for this period of flight. The Bureau of Aeronautics is taking preliminary steps to implement the development of a computer, if it should prove essential.

The problem of transition from beam riding to homing guidance is vital to the homing phase of the guidance problem. This phase of the guidance problem is being studied as directed by the Bureau of Aeronautics, by the Raytheon Mfg. Co., which is furnishing the homing guidance equipment. The Equipment Research Section of Radio Division III will, upon completion of the noise and dispersion beam riding flight tests, be able to predict within tolerable accuracy the probable position of the missile and the probable altitude of the bird with respect to the line-of-sight to the target of the radar beam. This information should be helpful to the contractor developing the equipment to accept and maintain control of the missile during the homing phase of the flight.

TELEMETERING REQUIREMENTS

An investigation of the availability of telemetering gear in the Lark and the probable requirements for mid-course guidance tests was initiated by Radio Division III. A conference was arranged with the Bureau of Aeronautics and it was decided by the Bureau representatives that the Princeton telemetering gear would be utilized to telemeter information for all beam guidance tests. When tests are made of missile behavior under beam guidance, sufficient channels for the requirements of the tests will be made available to the Naval Research Laboratory under primary priority. It was decided that the Naval Research Laboratory would not be required to supply any telemetering equipment for the tests.

INSTRUMENTATION REQUIREMENTS FOR TESTS

In the conduct of any test, it is necessary to insure that the instrumentation for the test is sufficient to cover all parameters under investigation. Furthermore, it is essential that the data taking methods be at least an order of accuracy better than the devices under test. It is desirable to reduce data analysis to a minimum in order to eliminate as much as possible delay time between tests and analysis of results, so that evaluation and preparation for additional tests may be made. The Operational Research Section was requested to investigate the instrumentation required for the tests outlined herein. The study is now underway, and will be augmented by a visit of Mr. J. J. Fleming to NAMTC, Pt. Mugu, California, to investigate the existing test facilities and to determine to what extent, if any, the Naval Research Laboratory may be of assistance.

The tests conducted by the Naval Research Laboratory on the beam riding guidance system, using the SNB as a test vehicle, can be accomplished with the instrumentation now provided. The instrumentation and method of conducting tests is described or recommended in the discussion of individual tests.

LOCALE OF TEST WORK

The tests by the Naval Research Laboratory, up to the present time, have been made at Fort Drum, Washington, D. C. The facilities of Fort Drum were loaned to the Naval Research Laboratory for use during World War II. The termination date of the use of these facilities has been announced as 30 June 1947. The SP-1 radar and instrumentation for test purposes will be removed from Fort Drum and relocated at the Chesapeake Bay Annex of the Naval Research Laboratory located at North Beach, Maryland.

The move will be made at the first convenient break in research work, probably at the conclusion of the receiver flight tests. Cabling for the new location is now under way, to minimize time lost from testing, but it is anticipated that the moving of equipment and reorientation of instrumentation will require from two to four weeks.

It is understood that all Lark beam guidance research will be made at NAMTC, Pt. Mugu, California.

ANALYSIS OF TEST DATA

The Operational Research Section of Radio Division III has been engaged for some time in obtaining and analyzing data concerned with the tests of anti-aircraft fire control equipment. Much attention has been directed toward instrumenting data analysis to reduce the time delay between data taking and test evaluation. Some of the devices developed for this purpose may be of use in the analysis of data of guided missile tests.

The Computer Mk 22, located at the Naval Research Laboratory, is a relay digital computer which has been used by both branches of military service for analysis of fire control test data. The computation desired is outlined upon a master tape; recorded data is punched upon a data tape; the computer automatically accomplishes the computation. The usefulness of the Computer Mk 22 may be extended to include computation of missile position in space from the transcription of photographically recorded data. The Operational Research Section of Radio Division III has been requested to investigate the possibility of using this computer and other instruments developed for data analysis with the view toward making them available for analysis of Lark test data, if desired. This will entail consultation with representatives of the Bureau of Aeronautics and those offices guiding the planning, both at the Bureau and at NAMTC. The progress of these studies and developments resulting from them will be reported as the occasion demands at the Lark-Wasp seminars. When conclusions have been developed and methods for accomplishment of data recording analysis arrived at and implemented, formal reports will be issued pertaining to this work.

SUPPORTING PROGRAMS

The Naval Research Laboratory is engaged in many programs, initiated for purposes of research and development unrelated in concept to Lark. The programs have resulted, in some instances, in the development of equipment that may adequately serve as part of alternate guidance systems, or may aid in widening the parameters of usefulness of the radar beam guidance system for the Lark or other missiles.

The major programs under way in Radio Division III that offer immediate potential application to missile guidance are: the high speed lobing radar, the simultaneous lobe comparison radar and the Hornet system of command guidance.

The high speed lobing radar differs from conventional sequentially lobed radars in that the lobing is accomplished electronically using switch tubes in the wave guides instead of by a mechanical scanning device. Electronic lobing of either the transmitted or received signal may be used. The switch tubes, developed under direction of Radio Division III, are now being applied to guidance systems under development at the Applied Physics Laboratory and Bureau of Standards. The high speed lobing radar has been developed, in the form of a laboratory built equipment, to the degree that it has achieved, in preliminary tests, automatic tracking at least as good as optical tracking. This development has a high potential use for either beam riding or command guidance and for scanning type homing guidance systems.

The simultaneous lobe comparison system, known as TAB, has been developed by Radio Division III to the point where automatic tracking tests are now under way. This system may be utilized as a tracking radar, or for beam riding or command guidance. Certain basic elements of the system are being developed by the Massachusetts Institute of Technology for use in homing guidance, and by Bell Telephone Laboratories and others for tracking radars.

The developments will be fully exploited to advance the fields of precision automatic tracking and missile guidance in all phases.

The Hornet system of missile guidance is a command system which utilizes pulse time modulation to automatically position the missile in the beam by command while the radar automatically tracks the target. Successful tests have been made, utilizing a receiver operative in one plane only; work is continuing, with the ultimate view of utilizing TAB as the radar for the system.

Some consideration has been given by Radio Division III to the development of an integrated beam-riding and passive homing system. Work on this project will be accelerated after accomplishing the development of the beam riding receiver.

CHAPTER VI

BEAM RIDER FLIGHT SIMULATOR

It became obvious, during the preliminary investigation of the many phases of developing a beam rider, that it would be necessary to devise a computer or simulator to develop the complex parameters of flight of a beam riding guidance system. After investigation of the possible types of simulators and computers for guided missiles, either developed or under development, it was decided that an analogue computer using a one-to-one time scale would be the most satisfactory for Laboratory purposes and the most simply constructed. The usefulness of such an instrument is extended if it is so constructed as to permit tests of control components as well as simulation of the missile in flight. The simulator is so designed as to be a component tester, under limited conditions.

This device generates target courses, simulates the response of the missile to transmitted intelligence and plots courses and errors of the missile. The trajectory of the missile is plotted in the co-target plane (the plane encompassing the guiding radar and the straight line projection of present target position to future target position) and in a vertical plane through the trajectory of the missile. The use of the described planes for plotting simplifies the geometric computations.

The simulator uses a transmitter and receiver which make it possible to explore the effects of noise and propagation phenomena on simulated missile trajectories. The missile is simulated, for purpose of mounting control components, by a two-axis servo driven gimbal system. The aerodynamic response of the missile is simulated by a network having the same transmission characteristics as the missile; the aerodynamic equations of motion are not separately solved.

The simulator will be used to reproduce, under controlled conditions, tests made on the missile, to evaluate the results of field tests and to explore limitations of the missile beyond the ability of field test work.

Two reports have been issued on the simulator, outlining the design philosophy and detailing the components involved in its construction. A program for its use is now being developed. Progress of the design and construction has been reported at Lark-Wasp seminars. Additional formal reports will be issued by the Naval Research Laboratory upon completion of the simulator and significant use in connection with the Lark-Wasp projects.

The simulator is being developed by the Equipment Research Section of Radio Division III. It is expected that it will be completed and ready for operation by early summer.

CHAPTER VII

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SNB AIRFRAME RESPONSE TESTS

Consideration of the airframe and autopilot combined indicate the necessity of establishing both the minimum and maximum bandwidths of the response characteristics of the combination of the airframe and autopilot.

In the examination of a missile guidance system as a closed loop servo, the minimum bandwidth is determined by the frequencies contained in the trajectory it is committed to follow (see Chapter V). The elements of the closed loop guidance system (i.e., the receiver, the control and equalization circuits, the autopilot and airframe) must transmit the band of frequencies required for intelligence of guidance without a cumulative phase shift that would create instability. The design of the closed loop must employ a safe phase margin, since variations in gain of the various elements, whether due to range or signal level, will modify both the phase shift at gain crossover and the transmission bandwidth of the components. In order that stably controlled beam rider flight may be accomplished, the phase shift contribution of each element and variations of signal, in both phase and amplitude, must be defined and maintained within tolerable limits. The design of the system has placed a limit on the phase shift contribution of the autopilot and airframe combination. The contribution of the autopilot and airframe combined, at gain crossover for the entire system must not be greater than a predetermined value under all conditions of operation. Thus the minimum bandwidth of the transmission characteristics of the autopilot and airframe may be determined.

The maximum bandwidth transmission characteristics of the combined autopilot and airframe must be determined to provide information for the design of the autopilot. If the bandwidth is too large, control becomes uneconomical; servo power is wasted and too great precision in manufacture is required. The maximum bandwidth can be determined by statistically gathering information as to the behavior of the airframe in flight, with controls locked, under conditions of varying winds and air density and other factors which may cause the airframe to deviate from a stable flight path. With the behavior of the airplane under these conditions known, it is possible to analyze the path followed by the airframe and to determine its frequency spectra. Investigation of the permissible error of deviation from flight path, will be made under conditions in which the missile is governed only by the autopilot controls (radar signal not guiding missile). Assuming tolerable errors and knowing the frequency spectra of the missile path, it is possible to determine the maximum bandwidth of the combined airframe and autopilot. From this information, it will be possible to specify the transmission characteristics of the autopilot controlling the airframe.

In the case of the Lark itself, an investigation must be made to determine the effect of the angle of attack control. It is entirely possible that the maximum transmission bandwidth established as herein discussed may be less than the minimum bandwidth determined by the tactical problem and the considerations of the closed loop of guidance. If this is the case, then only the minimum bandwidth need be considered in establishing specifications for the control equipment.

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TESTS FOR COMBINED AUTOPILOT AND AIRFRAME TRANSMISSION CHARACTERISTICS

The SNB airframe response tests have been accomplished by applying a constant amplitude variable frequency signal to the control servos of the modified P-1 autopilot and measuring the airframe response in flight. The measurements have been accomplished by tracking the airplane using a Gun Director Mk 51 stand mounting a camera with a telephoto lens. Photographic recordings were made of the bearing and elevation angle transmitted by the Mark 51 Director. Simultaneously, range to the airplane was obtained from the SP-1 radar and photographically recorded. With these three coordinates, the position of the bird in the space is determined and the amplitude of the output signal may be developed. The transmission characteristics of all components except the airframe are known by virtue of the SNB ground tests described in Chapter IV. Therefore, the response characteristics of the SNB in flight can be generated.

These tests were made by the Equipment Research Section, Radio Division III at Fort Drum, Washington, D. C. The only special instrumentation required for these tests was the modification of the Gun Director Mk 51 and installation of this instrument and the recording equipment at Fort Drum.

The photographic data will be analyzed by the Operational Research Section of Radio Division III, evaluation of the tests will be made by the Equipment Research Section. Results of the tests will be discussed at Lark seminars and a formal report will be issued upon completion of the tests.

TESTS TO DETERMINE MAXIMUM BANDWIDTH REQUIREMENTS

This test may be accomplished by flying the airplane in rough weather and measuring the deviations from the course with the autopilot preset. The transmission characteristics of the airframe and the controller are known. Knowing both the transmission characteristics and the errors, it is possible then to compute the frequencies imposed upon the loop. A check may be made by flying the airframe, without the autopilot, but with all controls centered. A measure of errors and a plot of the deviation from the assigned course can be subjected to harmonic analysis. This will determine the frequency spectrum operating on the airframe.

The tests will be made by personnel of the Equipment Research Section, Radio Division III, using the facilities allocated at Fort Drum. No special instrumentation will be required, tracking will be accomplished with the Gun Director Mk 51 as described in the preceding text. It is estimated that tests may be completed in April 1947. Data will be analyzed by the Operational Research Section, Radio Division III, and evaluated by the Equipment Research Section.

Results of these tests will be presented at a Lark-Wasp seminar and a report will be issued upon completion of the airframe response tests.

DESIGN AND DEVELOPMENT OF EQUALIZER CIRCUITS

Tests for determining response characteristics of the airframe and controller will be made with and without equalizer circuits in the loop. On the basis of the frequency response tests, the equalizer circuit established by the design specifications will be modified to account for variations indicated by tests and used on the SNB as a beam guided test vehicle.

DESIGN AND DEVELOPMENT OF EQUIVALENT RESPONSE CIRCUITS

When the response characteristics of the airframe and controller are known, circuits will be developed with equivalent response characteristics for two uses:

a) Use in the simulator for purposes of checking parameters of beam guided flight.
b) For noise tests.

The development of these circuits will be accomplished by the Equipment Research Section of Radio Division III.

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CHAPTER VIII

PILOTED SNB FLIGHT TESTS

The purpose of these tests will be to determine the behavior of the receiver and to obtain information to determine receiver requirements and specifications for production Lark receivers. The test, in addition to those tests directed at component circuitry, will be directed toward determining relationship between error (deviation from control line) and signal amplitude; reference stability under condition of varying signal strength and signal fading; and equivalent servo gain with range of the receiver. These tests will develop whether or not it will be necessary to design, develop, and test the use of the gyro and resolver to compensate for variations in roll of the missile.

The test will be accomplished by flying the plane into the SP-1 radar beam which will be fixed in direction. The pilot will, by cross pointer meters indicating the output of the receiver, attempt to fly the plane along the radar beam.

A camera with telephoto lens has been mounted on and boresighted with the SP-1 radar antenna. Photographic recordings will be made of the deviation of the SNB from the radar line of sight. Synchronized photographic recordings will be made of dials showing azimuth angle, elevation, and range transmitted from the SP radar and of the cross pointer meters located in the SNB. Recording will be made in the plane to indicate signal strength, and other parameters under investigation.

Tests will be made by the Beam Ways Section, Radio Division III, at Ft. Drum. Data will be analyzed by the Operational Research Section, evaluation of the tests will be made by the section heads and the project chairman. It is estimated that the piloted flight tests may be concluded in May 1947. The results of the tests will be presented at the Lark-Wasp seminar and formally reported when they have been concluded with significant success.

CHAPTER IX

MOBILE GROUND EQUIPMENT

Problem A-156R-S specified that an SP-1 shipborne radar be modified for transmitting intelligence to the missile in flight. The modification of the SP-1 radar was described in Chapter II. Because of weight and other physical restrictions, the SP-1 shipborne radar cannot be considered adaptable for field test use. A 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, will be modified for field test use.

The modifications required in the SP-1M are similar in detail to the modifications of the SP-1. The basic purpose of modifying the shipborne SP radar was to produce a radar suitable for fleet use and tactical operation while the modified SP-1M will be used only for test purposes. The double-gated automatic range circuits which will be used for tests are not considered necessary in the modification of the SP-1, but will be incorporated in the SP-1M. One gate will be used to automatically track the target in all coordinates in tactical tests; the second gate will be used to automatically track the Lark in range only. Special range circuits, calibrated to ±10 yards will be incorporated in the SP-1M. It may be desirable in testing the Lark as a beam rider that as much information as possible be obtained directly from the SP radar.

In order to utilize the SP-1M to track the Lark with a beacon mounted on the Lark, it is necessary to receive signals from the beacon at a different frequency than that utilized in the SP. To accomplish this, the construction of a second receiver for the beacon frequency is now under consideration.

CHAPTER X

NOISE AND DISPERSION TESTS

These tests are being made to determine the magnitude and effect of noise on the Lark-Wasp guidance system. The tests will be made using a receiver and the modified P-1 autopilot in the SNB airframe. The plane will be flown by the human pilot, guided by cross pointer meters, as nearly as possible on the beam center. A network having the equivalent of the transmission characteristics of the airframe, controller, and receiver, will accept the outputs of the receiver. The output from this network will be noise. The errors caused by noise can then be computed, and the noise as measured can be utilized in the simulator. The computation of error caused by noise will define the dispersion of the bird in beam guided flight.

These tests will be made by personnel of the Equipment Research Section, Radio Division III, utilizing the SNB and the SP-1 located at Fort Drum. There will be no special instrumentation other than the development of the network described above. It is estimated that significant data can be obtained from these tests before May 1947, if unforeseen difficulties do not develop.

Data will be taken in the form of photographic records and instrumental recording in the plane. The Operational Research Section of Radio Division III will assist in the analyzing of data. The tests will be evaluated by the Equipment Research Section. There will be preliminary discussion of the test results at Lark-Wasp seminars and a formal report issued by the Laboratory on conclusion of the tests.

CHAPTER XI

SNB BEAM RIDING TESTS

It is planned to make tests under static conditions (i.e., beam not in motion), of the accuracy, the attitude, the dispersion, etc., of the SNB in beam-riding, automatically controlled flight. Dynamic response tests will be made to determine the response of the SNB guidance and control components as a completely closed servo loop. Tactical examination of the behavior of the bird will be made by programming various target courses into the antenna servos of the SP-1 radar and observing behavior of the bird in attempting to intercept the simulated target.

STATIC TESTS

The static tests will be accomplished by manually flying the SNB into the beam, switching to beam riding guidance, and permitting the SNB to fly out the stationary beam. This test will use closed loop guidance, including equalizer circuits designed from previous tests, and with the transmission bandwidth of the closed loop established as required for tactical conditions. Test data will be recorded by the use of cameras, boresighted with the radar line of sight, which will photograph the position of the airplane with respect to the line of sight of the radar beam. Synchronized cameras will simultaneously record the bearing, elevation, and range transmitted from the SP-1 radar. Other synchronized cameras, located in the SNB, will record flight data pertinent to the tests.

From the analysis of test data, there can be determined much information pertinent to the launching of missiles and their capture by the radar beam. These tests and succeeding SNB beam guided flight tests will correlate predicted accuracy and dispersion of the beam guided flights with the actual observed results.

These tests will be made by members of the Beam Ways Section of Radio Division III, at CBA or Fort Drum, depending upon the location of the SP transmitter at the time of tests. It is expected that these tests will be completed by 1 June. It is not anticipated that any additional instrumentation will be required for these tests.

Data will be analyzed by the Operational Research Section. Evaluation of the results will be made by Radio Division III.

DYNAMIC TESTS

Dynamic tests will be made with the SNB receiver operating in a closed loop of guidance. Signals will be imposed upon the servos of the SP radar so as to introduce constant amplitude variable frequency signals over the frequency range desired for tactical operation. Performance of the plane will be observed by cameras mounted on the radar antenna and boresighted with the radar line-of-sight. Information will be photographically recorded as to the amplitude and frequency of input using dials on the SP radar indicating bearing, elevation angle and range. From these tests, the transmission characteristics

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of the system as a closed loop can be checked against the design specifications established by the bandwidth studies.

These tests will be made by members of the Beam Ways Section and the Equipment Research Section, Radio Division III, probably at CBA after the relocation of the SP radar. It is estimated that these tests should be completed by 1 July 1947. There will be no special instrumentation required for these tests.

The results of these tests will be evaluated by the Equipment Research Section. Evaluation of these tests will permit a prediction of the behavior of this missile under tactical programming or tactical operation.

TACTICAL TESTS

It is desired to evaluate, for use of the Fleet, the behavior of this receiver and allied components under tactical conditions. While it is true the use of the receiver in an SNB cannot be conceived to be a tactical weapon, yet tests of this character will develop the necessary knowledge for the prognostication of the behavior of tactical missiles which cannot be used for tests under controlled conditions. These tests will use a programming device to insert signals into the servo of the SP-1 that will result in the apparent automatic tracking of a known target having a prescribed tactical course or mission. The missile will be captured by the beam and is expected to fly out the beam in accordance with the errors predicted from the preceding tests discussed in this chapter. If the simulated missile falls within the predicted errors as evaluated by the static and dynamic tests, it becomes evident that corollary evidence has been developed to permit evaluation of tactical missiles.

These tests will be accomplished by personnel from the Beam Ways Section and Equipment Research Section of Radio Division III. They will be made with the SP-1 radar located at the Chesapeake Bay Annex. It is estimated that these tests will be completed by 1 September 1947. No special instrumentation will be required for these tests. Data will be obtained in the form of photographic recordings and analyzed by the Operational Research Section of Radio Division III.

Evaluation will be made by sections of Radio Division III. Further tests will be made as the need is indicated or as requested by the Naval Bureaus.

CHAPTER XII

DESIGN AND CONSTRUCTION OF PRODUCTION RECEIVERS

Problem A-156R-S requires the design and construction of one prototype receiver. It is felt desirable to construct several Laboratory-built models of the receivers. The Laboratory will construct six beam riding receivers of design such as to permit them to be installed in the Lark. Modifications of the design will be made as such modifications are indicated by analysis and evaluation of test results.

The problem of interconnecting the outputs of the beam riding receiver to the Flight Control Assembly, manufactured by Raytheon Mfg. Co., to achieve beam-riding control of the Lark, is under investigation by the Avigation Section of Radio Division III. Several means of accomplishing this are being devised; the most economical of space and weight will be adapted as part of the receiver.

The total quantity of receivers required for research is being determined by the Bureau of Aeronautics in conjunction with their plans for beam riding flights of the bird.

CHAPTER XIII

STATIC TESTS OF LARK AND RECEIVER

Before any beam riding flights of the Lark are made, it is recommended that the following information be developed:

a) Frequency response characteristics of the beam riding receiver
b) Frequency response characteristics of the FCA
c) Frequency response characteristics of the control servos
d) Frequency response characteristics of the airframe with roll stabilization and including angle of attack control, if used.
e) Design of equalizer and bandwidth limiting circuits for closed loop guidance
f) Determination of noise in flight
g) Interaction of components

FREQUENCY RESPONSE CHARACTERISTICS OF THE BEAM RIDING RECEIVER

The laboratory-built, prototype and production beam riding receivers will be designed to have a flat frequency response, approaching theoretical limits established by the radar scan frequency as closely as possible, to minimize any contribution to phase shift from this source. Tests will be made by the Beam Ways Section of Radio Division III on laboratory-built receivers, and by the manufacturer on production built receivers. The time of completion of these tests is contingent upon completion of design and construction of production receivers.

FREQUENCY RESPONSE CHARACTERISTICS OF THE FLIGHT CONTROL ASSEMBLY

A production model of the Flight Control Assembly will be tested to determine the frequency response of the gyros to signals applied to them, as if from the beam riding receiver, and in response to the stimuli of external motion.

Constant amplitude, variable frequency sinusoidal signals will be applied to the torque motors of the FCA gyros and the response measured at the output of the gyro pick-offs. The FCA will be mounted upon a test table and subjected to sinusoidal input motion, of constant maximum velocity in both input planes and the output of the gyros examined for both response and crosstalk.

Measurements of drift of the gyros will be made to determine if performance requirements for control of the missile in the absence of radar signals will be met.

The frequency response tests of the FCA are being made by the Avigation Section of Radio Division III. Evaluation of the results will be made by the Equipment Research Section. The tests will be completed in April 1947.

It is recommended that the output of the FCA be examined in the presence of motor vibration. This can be accomplished in the course of the noise and vibration tests being made at NAMTC, Pt. Mugu, California; by telemetering FCA outputs in flight; or by simulated vibration and shock. Spurious outputs from the FCA caused by motor vibration, will create an effect similar to noise in the transmitted control signal causing dispersion of the missile and wastage of servo power. It is recommended that tests of the effect of motor noise and vibration of the FCA be made by NAMTC, Pt. Mugu, California.

FREQUENCY RESPONSE CHARACTERISTICS OF SERVO SYSTEMS

It is recommended that the frequency response characteristics of the control servos be determined to establish the contribution to total phase shift caused by those components. It is recommended that these tests be accomplished by imposing constant amplitude variable frequency sinusoidal signals upon the torque motors of the gyros of the FCA and recording the outputs of the control surfaces. Additional tests are recommended in order to observe the response of the control surfaces of the missile to the stimuli of external motion of the missile. It is recognized that these ground tests of the missile controls do not include the loads on the servos encountered in flight, but it is presumed that the servos are capable of accepting the applied loads. It is recommended that these tests be accomplished by the individual airframe contractors.

FREQUENCY RESPONSE OF THE AIRFRAME

It is recommended that the frequency response of both the KAQ-1 and KAY-1 airframes, including roll stabilization and angle of attack control be investigated. This can be accomplished in a preliminary manner by a simulator study. The results of the simulator studies should be confirmed by flight tests.

Flight tests may be made by programming input signals into the FCA and recording the output as the position of the bird in flight.

It is recommended that the calculated frequency response and the response tests be accomplished by the airframe contractors, using NAMTC facilities.

DESIGN OF EQUALIZER AND BANDWIDTH LIMITING CIRCUITS

The results of the preceding static tests of Lark control components, with the background of laboratory tests, will permit the design of equalizer and bandwidth limiting circuits to insure stable beam guided flight of the missile operating as a closed loop servo. The Equipment Research Section of Radio Division III will design the required circuits subsequent to the evaluation of test information. A circuit simulating the response characteristics of the bird and control components, also will be developed for use in the simulator and in noise tests.

DETERMINATION OF NOISE IN FLIGHT

Noise in the guidance system will be a major factor in contributing to waste of servo power and errors in beam riding flight.

Noise tests using the SNB as a test vehicle will indicate the magnitude and effect of noise contributed by the transmitting radar, the medium through which the wave is propagated and the receiver, but will not show the contributic caused by the propelling flame nor indicate the effect of reflected signals at missile speed.

It is recommended that these tests be accomplished at NAMTC, Pt. Mugu, with a beam riding receiver in the missile, the outputs of which are fed into a circuit simulating the bird and control response, developed as described previously in Chapter X. The bird shall be flown out the radar beam and automatically tracked by the radar. The output from the network simulating the bird is the noise of the system. The noise signals shall be telemetered by an accurate telemetering device. The noise contributions of the telemetering gear and the automatic tracking servos shall be isolated to determine the guiding system noise. From this and previous tests, the noise contribution of the propelling flame may be isolated, if desired.

It is recommended that the tests be accomplished by personnel of NAMTC, Pt. Mugu.

INTERACTION OF COMPONENTS

Problem A-285T-C, assigned to the Naval Research Laboratory by the Bureau of Aeronautics, involves the examination of all electronic and electrical equipment installed in the Lark to determine if electrical interference or interaction exists and that the equipment performs the desired operations in the most satisfactory manner. This test work is being accomplished by the Avigation Section of Radio Division III.

SUMMARY OF STATIC TESTS

On the basis of the tests of the components of the guidance system, the airframe, and the composite behavior of the assembled equipment, it will be possible to predict the accuracy and behavior of the missile in beam guided flight. Most important, however, is that underlying the prediction will be the understanding of the behavior of all components and the requirements to design a stable beam riding missile.

CHAPTER XIV

LARK BEAM RIDING TESTS

It is recommended that the Lark beam riding tests be directed toward accomplishing the following:

a) Beam riding guidance using a stationary beam.
b) Beam riding guidance in tactical flight.
c) Correlation of predicted with realized performance.

BEAM RIDING GUIDANCE USING A STATIONARY BEAM

This test shall determine the accuracy of beam guided flight of the Lark in a stationary beam. Errors in flight using a stationary beam are caused by the spurious signals of noise if the closed loop servo system is stable. It is recommended that this test shall be accomplished by launching the missile into the beam (automatically tracking the missile with the beam if necessary because of launching dispersion,using a known bandpass in the auto-tracking circuits), and recording the accuracy of the missile with respect to the radar line of sight. Since the beam is stationary, the dispersion measured in the closed loop flight will be caused by system noise. The results of this test should be correlated with the noise tests previously described.

BEAM RIDING GUIDANCE IN TACTICAL FLIGHT

Tactical flight tests may be accomplished in two ways. If the dispersions of the tactical launcher and pre-capture flight are either unknown or too great to consistently accomplish beam capture of the missile, it will be necessary to acquire the missile by the radar after launching and having established that the missile has been captured, transfer to a programmed guided tactical course. Position of the missile and programming of the radar beam shall be recorded for evaluation of the performance of the missile.

When a launcher for tactical use has been developed to the point where capture by the radar beam may be accomplished with adequate success, then complete tactical analysis may be made by programming the guiding radar as if it were tracking a target, firing the missile into the moving beam and recording the position of the bird with respect to the line of sight of the beam.

CORRELATION OF PREDICTED PERFORMANCE WITH REALIZED PERFORMANCE

It is recommended that all beam riding tests be conducted by personnel of NAMTC, Pt. Mugu, under supervision of the airframe contractor for aerodynamic details.

Prior to the actual beam riding tests programmed to guide the missile along a prescribed tactical course, an analysis of each test course will be made in an attempt to predict the behavior of the missile from bench tests, SNB flight tests, and static tests of the Lark previously made. If there is sufficient correlation of the predicted results with the realized results in tests, then there has been established a technique which will be of extremely significant value for examining the behavior of tactical missiles under tactical conditions, one which will be economical of time, money, and materials when applied to future developments.

CHAPTER XV

BEAM GUIDING PLUS HOMING TESTS

It is recommended that tests of beam guidance plus homing be directed to the following: (1) programmed beam guided flight in which the bird would be directed toward a stationary target until the range is reached when homing would take control of the bird, (2) beam guided flight tests directed to ultimate homing on a drone utilized as a cooperative target.

FLIGHT TESTS ON STATIONARY TARGET

It is recommended that the missile be guided by the SP-1M to a point within the range of the homing device to take control of the missile. At this point, an automatic transition must occur between guidance and homing. To examine all parameters of the flight, the transitional period must occur at a minimum range to the place of data taking. It may be desirable, because of the characteristics of the homing system, to confine beam guidance plus homing tests to moving targets. The use of a stationary target in the initial tests is recommended to keep as many parameters under control as possible and to simplify data taking and analysis.

It is recommended that these tests be made by the personnel of NAMTC, Pt. Mugu, under the guidance of the manufacturer of the homing equipment and the cognizant airframe contractor.

FLIGHT TESTS ON MOVING TARGETS

It is recommended that beam guided plus homing guided tests be made, using a cooperative moving target. To make such a test, it will be necessary to fly a drone within the range of tracking radar, to release and to capture the bird, and to guide it by the radar until the period of transition to homing and then to observe the behavior of the missile while homing on a moving target.

It is recommended that such tests will be conducted by the personnel of NAMTC, Pt. Mugu, and that the direction of these tests be accomplished by the airframe manufacturers and control equipment manufacturers.

CHAPTER XVI

TACTICAL PROBLEMS

In the examination of the Lark as a tactical missile, or in obtaining data sufficient to indicate a method of inspection of any missile for tactical purposes, it is recommended that the work be divided into two parts: (1) Flight tests on prescribed tactical problems, (2) Theoretical studies on the behavior of the missile and guidance systems used for tactical problems.

FLIGHT TESTS ON PRESCRIBED TACTICAL PROBLEMS

It is recommended that the Bureau of Aeronautics develop the tactical target courses for which the Lark might be used. For purposes of testing the target will probably be a drone, flown on a prescribed tactical course, but not behaving as a cooperative target. Performance of the missile under these circumstances will be an index as to its tactical abilities. The information, the understanding, the means, the test instrumentation, the many devices, and problems which go into the completion of these tests, will show the way for future tests of guided missiles. In a large sense, these tests will not only be the culmination of developing the Lark as an experimental test vehicle, but will develop a technique of testing and analysis which can be utilized on any form of guided missile. These tests will serve to correlate theoretical predictions of the behavior of missiles and guidance system with realized performance. Having established the existence of such correlation, design of future missiles may be accomplished with a minimum expenditure of time, error and money.

It is recommended that such tests be conducted by NAMTC, Pt. Mugu, under the guidance of the contractors.

THEORETICAL STUDIES ON BEHAVIOR OF COMPLETE MISSILE ON TACTICAL PROBLEM

From the information compiled from the tests described, it should be possible to develop a method of analyzing guided missile problems and specific guided missiles, in addition to evaluating the Lark itself as a tactical weapon. From this information any tactical problem may be analyzed and determination made as to the effectiveness of the Lark as a tactical weapon for that problem. Assignment of definite tactical problems to be investigated should be made by the cognizant bureau. The investigation of the behavior of this missile or any similar beam guided missile may be made by Radio Division III of the Naval Research Laboratory. The scope of theoretical studies of this character should be determined by the cognizant Naval bureau and the Naval Research Laboratory.