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Quarterly Progress Report No. 1
December 31, 1946

Air Documents Division, T-2
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PROJECT KINGFISHER

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NATIONAL BUREAU OF STANDARDS

PROJECT KINGFISHER

QUARTERLY PROGRESS REPORT NO. 1

COVERING ACTIVITIES THROUGH DEC. 31, 1946

SUBMITTED TO:

BUREAU OF ORDNANCE
(Re9e)
NAVY DEPARTMENT

APPROVED FOR NBS:

Hugh L. Dryden CHIEF OF PROJECT

E. U. Condon DIRECTOR, NATIONAL BUREAU OF STANDARDS

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Experimental Type A

KINGFISHER

(SWOD Mark 15 Airframe)
Mounted on wing of PB4Y-2
for test flight

U 93

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PREFACE

This is the first quarterly progress report on Project KINGFISHER. Previous progress reports were issued first weekly and later monthly up through October 1946. In this first quarterly report, an over-all summary of progress from the beginning of the program to December 31, 1946, has been included.

Reference in the following report to previous or more detailed reports is made by superscript numerals, the number corresponding to the listing in the Bibliography.

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I. INTRODUCTION

The KINGFISHER is a radar-controlled, subsonic, self-homing, airborne guided missile designed to deliver an explosive charge below the waterline against floating targets. It is intended that KINGFISHER be released from an aircraft well beyond the range of conventional antiaircraft fire originating at the target. The KINGFISHER, in turn, will release a torpedo at some distance short of the target.

Project KINGFISHER is an outgrowth of the PELICAN and BAT Projects, which were carried on, during the war, at the National Bureau of Standards under the sponsorship of the National Defense Research Committee and the Bureau of Ordnance, Navy Department. First design consideration was given to KINGFISHER in September 1944, when the Bureau of Ordnance requested that a homing glide missile be developed capable of carrying an aircraft torpedo as payload, designed to enter the water short of the target, completing its run under water. However, very little was done at that time because of the need for concentration of efforts on the BAT development.

In November 1945, the Navy Department transferred cognizance of the BAT to the Bureau of Aeronautics but retained cognizance of KINGFISHER in the Bureau of Ordnance. The M.I.T. field experiment station which had worked on the electronic part of the development of PELICAN and BAT was no longer available for continuation of the work. At this time, the National Bureau of Standards was requested to undertake the over-all development of KINGFISHER. The organizational setup at NBS for Project KINGFISHER is shown in Figure 1.

At present, five KINGFISHER type missiles have been prescribed for development:

Type A: SWOD Mark 11

> To be a gravity-driven vehicle having a 20-mile range, launched from an aircraft at high altitude; total weight of unit to be about 3,000 pounds, including the payload, a Mark 21 acoustic homing torpedo.

Type B: To be a gravity-driven vehicle having a 20-mile range, launched from an aircraft at high altitude; total weight of unit to be about 1,000 pounds, including the payload, a 550-pound non-powered non-homing bomb-torpedo similar to the German BT.

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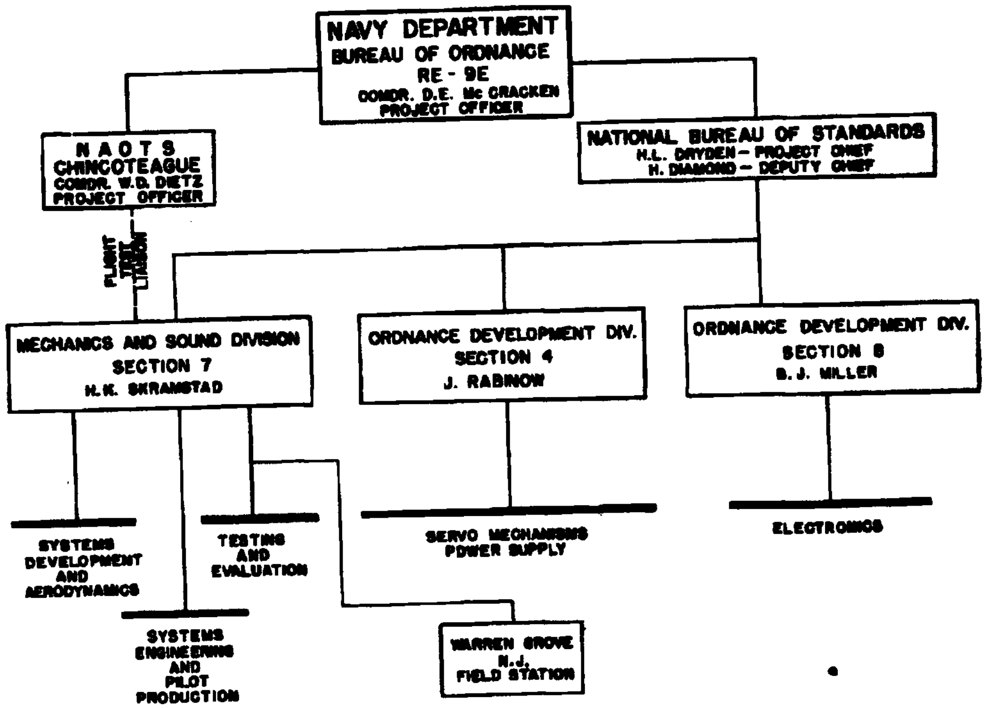

FIGURE 1 - ORGANIZATION CHART FOR RESEARCH AND DEVELOPMENT OF PROJECT KINGFISHER

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Type C: To be a power-driven missile having a 20-mile range when launched from an aircraft at low altitude; total weight of the unit to be about 4,000 pounds, including the payload, a power-driven homing torpedo having a 350-pound warhead charge.

Type D: To be a power-driven missile having a 20-mile range when launched from an aircraft at low altitude; total weight of the unit to be about 3,000 pounds, including the payload, a light-weight power-driven homing torpedo (yet to be developed) having a 200- to 400-pound warhead charge.

Type E: To be a power-driven missile having a 10- to 20-mile range when launched from a surface ship; total weight of the unit to be about 3,000 pounds, including the deep-diving homing torpedo now in the research stage.

Although all five types are being given consideration, initial development is concentrated on Type A, with appreciable parallel work on Type B.[1,2,3]

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II. STATUS OF DEVELOPMENT

A. AIRFRAME

First design consideration for an airframe for KINGFISHER was for a glide missile capable of carrying a standard Mark 13 aircraft torpedo. The use of this payload presented several requirements that combined to complicate the design of an airframe with radar homing intelligence. Since the torpedo is more than twice as long as a G.P. bomb of comparable weight, problems of adequate airframe rigidity for an allowable weight are somewhat more difficult than for BAT. Also, the payload has to be released before water entry.

Aerodynamically, the necessity of having the electronic homing intelligence ahead of this long payload imposed problems of adequate stability to cope with the large longitudinal moment of inertia. Then, too, the required water entry attitude made it desirable to incorporate the aerodynamic control system already in use on the BAT glide bomb. This system has the advantage of producing large changes in the value of the lift vector with small change in the angle of attack.

Since the first work on KINGFISHER was done as a low-priority phase of the BAT Project, it was deemed advisable to adapt as many component parts of the BAT airframe as feasible. This would not only facilitate manufacture by the use of existing forms and jigs, but also be of value in service because of interchangeability. Consideration, therefore, was given to the idea of modifying the existing 2,000-pound BAT airframe (SWOD Mark 14) by redesigning the body to accommodate a releasable torpedo payload. However, upon some analysis, it was found that for adequate structural stability, the body would be excessively heavy and bulky with the obvious disadvantage of handling in service. It was concluded, therefore, that it would be advantageous to attach the main supporting wings and the stabilizing empennage directly to the torpedo. With this in mind, an arrangement was devised that made use of the existing Mark 14 BAT wings with simple pin attachments to a central frame which, in turn, was strapped to the torpedo near its center of gravity. This central frame formed a superstructure in which were housed the batteries, the servo, and some of the electronic equipment. The straps that held this assembly to the torpedo terminated at a standard 14-inch bomb shackle, thus allowing release of the wings by some electrical initiator prior to water entry. At the same time, the nose and tail assemblies could be detached by means of a cable release latch.

A 1/8-scale model of this design was made and tested in a wind tunnel at NBS. The results of these tests showed acceptable performance characteristics. Five full-scale KINGFISHER airframes were then ordered from the Vidal Research Corporation, which had available the molds and jigs for the BAT airframes. Two of these airframes were assembled on dummy Mark 13 torpedoes and prepared for flight test. The decalage (angle between the chord of the wing and the horizontal tail surface) was set at 2.5°, which was the best adjustment from wind tunnel tests of the model. These units

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were equipped with a release mechanism for shedding the nose, wing and tail assemblies after 30 seconds of flight. These units contained no homing equipment but were roll-stabilized, using the standard control gyro SWOD Mark 6 and servo SWOD Mark 5 Mod 0.

The first unit (Flight K-9, June 11, 1946) was launched at 180 knots from an altitude of 4,000 feet. It descended at an angle of about 34° to the horizontal. Stabilization in roll was obtained, but with a larger roll hunt amplitude than is normal with the BAT missile. The missile hit the ground before the release mechanism had time to operate. The second unit (Flight K-10) was launched at 200 knots from an altitude of 6,000 feet. It descended at a glide angle of 29° to the horizontal, making a steady flight. The release mechanism operated successfully at 30 seconds at an altitude of about 1,000 feet.[4] The results of these tests were considered sufficiently satisfactory to allow use of this airframe (designated as SWOD Mark 15) as an interim test vehicle for future development of new radar homing equipment. Figure 2 shows a photograph of the Mark 15 KINGFISHER airframe.

To this end, a contract was let to Camden Eastern Marine Company to build 19 additional plywood airframes using the Mark 14 BAT wings then on hand. Later, another contract was let to the Goodyear Aircraft Company to reproduce this airframe in metal because this material lends itself to quantity production. Also, service experience with the BAT airframe showed that undesirable warping occurred when the plywood structures were subjected to adverse climatic conditions.

In November, two additional flight tests were made of the Mark 15 airframe. Since the first two units tested (Flights K-9 and K-10) descended too steeply, the decalage was increased to 3° on one unit and 3.5° on the second unit. Each missile was equipped with Mark 1 (PELICAN) radar equipment for homing against a stationary beacon. The first unit (Flight K-23) was released at 200 knots. It displayed a rather large roll hunt amplitude during flight and landed about 1 mile short of the target. The second unit (Flight K-24) dropped away normally but after about three seconds attained a steep angle of bank and descended in a spiral, landing at a point nearly below the release point. Records obtained showed that a failure occurred in the radar equipment. Failure of the first unit to reach the target seems to be due to the effect of the large roll hunt amplitude on the operation of the pitch gyro. Changes are being made in the next units to correct this condition.

Since more compact radar homing equipment is in process of development (See Part C), it seems desirable to simplify the airframe to the extent of eliminating the body portion. It was first proposed to attach the wings directly to the torpedo by means of latches incorporated in the torpedo structure. Analysis of this, however, showed that latches could not be placed at appropriate positions because of interference with the torpedo's airflask. An arrangement was then devised to strap the wings directly. This has certain advantages for testing, in that the wing may be shifted longitudinally to compensate for any change in the position of the center

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FIGURE 2 - SWOD MARK 15 AIRFRAME FOR KINGFISHER

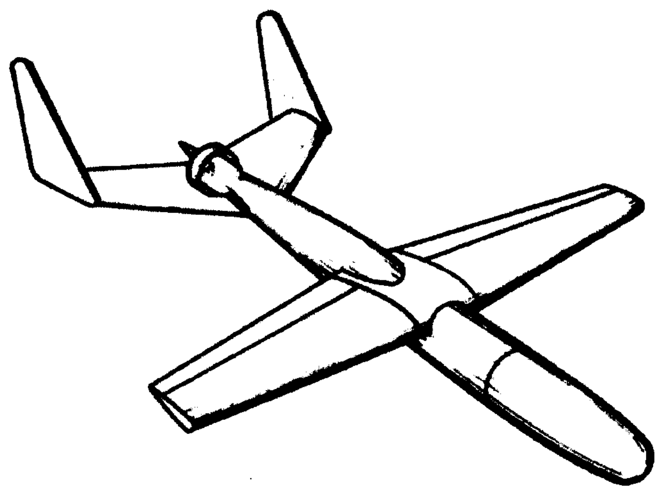

FIGURE 3 - FIRST PROTOTYPE OF WING-ATTACHED AIRFRAME
FOR KINGFISHER TYPE A SWOD MARK 11

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of gravity. The flexibility of this design lends itself to the conversion into a Type C powered missile, in which case it is proposed to attach a turbo-jet motor to the rear of the shroud ring assembly of the torpedo tail. Wind tunnel tests of 1/6-scale model of this design are now in progress, and results to date are exceedingly gratifying. The structural design for a full-scale version is well under way. With the completion of these drawings, a full-scale prototype will be made for flight test. A sketch of this design is shown in Figure 3.

Tentative designs for the payload for Type B KINGFISHER have been worked up and submitted to the Navy for evaluation of the hydrodynamic characteristics. Two designs were included, one for a 500-pound payload, 14 inches in diameter, and the other with a 260-pound payload, 11 inches in diameter. Tentative designs have also been prepared for the wing attachments and tail assemblies for these payloads. However, models will not be prepared for wind tunnel tests until miniaturization of the intelligence system has progressed to the point where specification of practical limits of its size and shape is possible. (See Part II-C of this report)

B. NAVIGATION

Past experience with BAT, as well as numerous mathematical studies, has shown the pursuit-course type of homing to be inadequate for use against fast-moving targets. Accordingly, it was decided that some type of course navigation would be desirable for the KINGFISHER missile.[11] Any type of automatic navigation which causes the missile to fly a course differing from a pursuit course must cause the missile to fly at an angle to the line-of-sight path. Therefore, the homing reference axes can no longer remain in a fixed relation to the missile axes. Since the stabilization system of the missile is referred to missile axes, undesirable cross effects might occur in the homing signals due to the divergence of the two axes when the missile changes its attitude, especially in the case of a rolling motion. These cross effects might seriously affect either the stability or the accuracy of the missile. It is expected that with adequate computers for both azimuth and elevation, difficulties from cross effects will be resolved.

At the close of the war, many missiles and missile components remained from the PELICAN and BAT development programs. Since these units were surplus and readily available, a series of tests, preliminary in nature, were outlined to demonstrate the practicability of using course computers in homing missiles.

For tests of this nature against moving targets, an 8,000-foot railroad had been constructed at the Warren Grove, New Jersey, Test Field. The target, which is a radar beacon, is mounted on a railroad section car. After starting, the car runs unattended with a pre-set speed. Track switches along the railroad automatically record the target position at various time intervals and operate mechanisms to stop the car at the end of the track.

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During the first three months of 1946, 8 PELICANS (SWOD Mark 7 Mod 0) were dropped on the moving target at Warren Grove (Flights K-1 to K-8).[4] The antennas of two of these units were offset in asimuth by fixed lead angles of 12° and 8°, respectively, estimated to give true collision course compensation for the particular flight conditions. On two other units where the target moved at 48 mph, the antennas were offset by an amount less than that required to produce a true collision course. The antenna of one of these was offset by 1/2 the full value, or 6°, and that of the other, by 3/4 the full amount, or 9°. For comparison, the other four units were dropped with zero lead angle compensation.

In all of those tests, the asimuth flight path was according to expectations. In the case of the two with fulllead angle compensation, the flight path was very straight throughout the major portion of the flight. However, since the line of flight passed the target path slightly ahead of the target, it may be concluded that the lead angle was a little too large. The two units with 1/2 and 3/4 of full collision course lead angle flew a modified collision course path with a slight curvature in the direction of target motion, with their line of flight passing the target path slightly behind the target. The four units with zero lead angle all flew typical pursuit paths, with their line of flight passing the target path behind the target. Examination of the flight charts of these tests reveals no adverse effect on the stability of the glider when the antenna is offset in asimuth. However, the accuracy in range was considerably influenced by the squint angle (the angle between the effective zero axis of the antenna and the axis of the missile). A fairly large dispersion in range could be expected when the antenna assembly is offset in asimuth but fixed in pitch, because for this condition, a pitch error is introduced whenever the glider banks to correct for an asimuth error Figure 4 is a typical example of a flight path obtained against a moving target with lead angle compensation on the antenna; Figure 5 is an example of the type of path obtained with zero lead angle.

For the purpose of investigating the feasibility of using Flettner type flaps for control of the KINGFISHER missile, two Mark 13 airframes were provided with auxiliary control surfaces attached to the elevons and operated by standard White-Rodgers servo motors in each elevon. Mark 1 (PELICAN) homing equipment was provided in the missile for homing on a fixed beacon. These units were dropped at the Warren Grove Test Area in June (Flights K-11 and K-12). Neither of the units homed but showed successful roll stabilisation. The rates of roll developed in the roll hunting motion were very large, and failure to home can be accounted for by the effect of these high rates of roll on the action of the gyros. Further experiments are contemplated with modified arrangements.

In order to investigate the performance of a simplified lead computer system, four SWOD Mark 8 Mod 0 units, containing lead computers in asimuth, were dropped against a beacon carried on a moving target car at the test field at Warren Grove, New Jersey, during July 1946. Each unit contained Mark 1 (PELICAN) radar homing equipment, and the antennas of all units were arranged so that they could be rotated in asimuth by White-Rodgers reversible motor servos.

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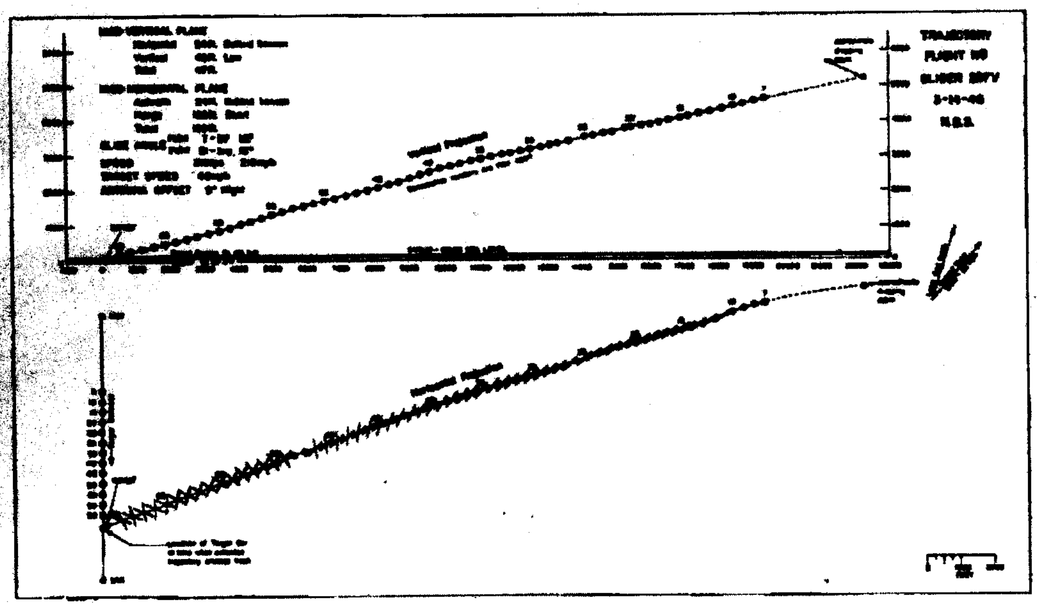

FIGURE 4 - HORIZONTAL AND VERTICAL PROJECTIONS OF TRAJECTORIES IN KINGFISHER FLIGHT TEST K-8.
(The intersecting lines on the horizontal projection represent the actual location of trajectory points as obtained from two observation stations.)

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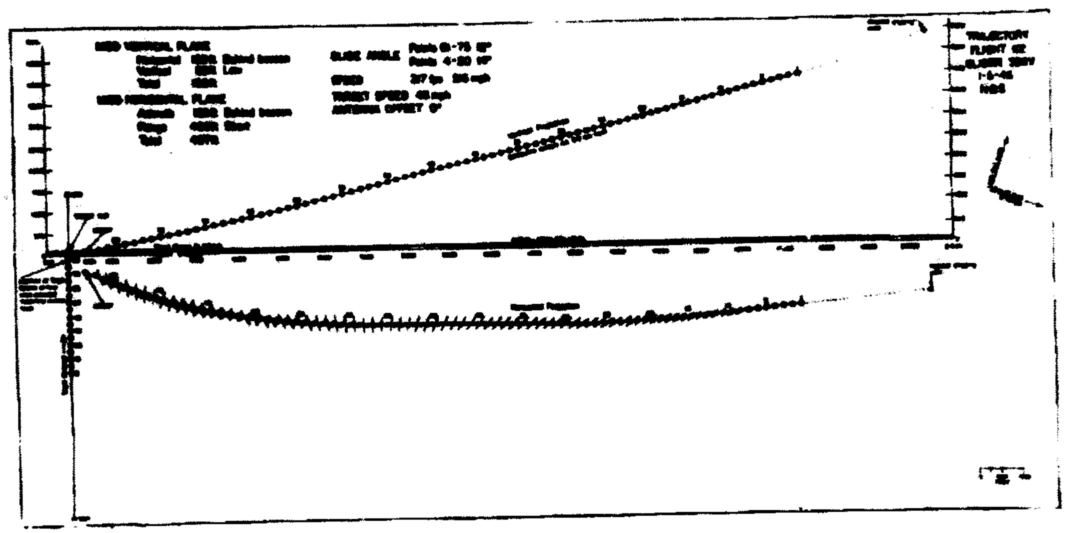

FIGURE 5 - HORIZONTAL AND VERTICAL PROJECTIONS OF TRAJECTORY IN KINGFISHER FLIGHT TEST K-2

[redacted]

Two units contained a rate gyro sensitive to yaw, with circuits arranged so that the antenna rotated at constant speed to the right when the sense of the rate of yaw was to the left, and to the left at constant speed when the rate of yaw was to the right. The other two units contained relays in the output circuit of the radar homing unit, with circuit arranged so that the antenna would be turned to the right at constant speed for a left error signal and to the left for a right error signal. The speed of rotation of the antenna in azimuth for one unit of each type was .5°/sec and the other, .8°/sec. The target speed on all tests was approximately 60 ft/sec.

Although as yet the camera data have not been analyzed, the performance of the units as determined by observers at the test field was not very satisfactory. One unit with the rate of yaw gyro control on antenna motion (Flight K-13) failed to home due to failure of homing equipment in the missile. The other, Flight K-14, landed about 1,200 feet short of the target. One unit with the error signal control on the antenna motion, Flight K-15, passed 290 feet ahead of the target car, landing about 25 feet over the track, and the other unit (Flight K-16) about 700 feet short and whose flight trajectory extended would intersect the track 58 feet ahead of the car's position at time of crossing.

In order to investigate the performance of another lead computing system in azimuth, six SWOD Mark 8 Mod 0 units were tested against a moving target at Warren Grove during August and November, 1946. These tests were made for the purpose of checking a partial navigating system in azimuth. Three of these units were arranged so that the antenna was rotated in azimuth through one-half the angle turned by the missile from its heading just prior to release (navigation correction factor, 2). On three units the antenna was turned relative to the missile three-fourths the angle turned by the missile from its heading just prior to release (navigation correction factor, 4).

Of the three missiles with navigation factor 2, the first unit (Flight K-17) landed about 1,000 feet over the railroad and crossed about 400 feet ahead of the target car. The second unit (Flight K-18) crossed the railroad about 150 feet behind the car and about 14 feet short of the beacon. The third unit (Flight K-19) lost tracking of its homing signal on release and thus made a non-homing free flight. The first unit with navigation correction factor 4 (Flight K-20) passed about 150 feet ahead of the car and was about 25 feet short of the beacon. The second unit (Flight K-21) landed 300 feet behind and 600 feet over the target car. The third unit (Flight K-22) landed about 1,000 feet short and 100 feet behind the car. All releases were made from approximately 5,000 feet, at a glide angle of 4.5° to 1° and at an air speed of 160 knots. The speed of the target car in each case was approximately 60 ft/sec. Although the errors were fairly large, with rather large scatter, the accuracy in azimuth is estimated to be better than would be obtained on a target moving at that speed without a navigation system.

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C. INTELLIGENCE

1. Analysis of Basic Systems

The analysis of intelligence systems for KINGFISHER has been confined to active radio homing (active implying self-contained transmitter) and to the X Band. Two basic systems within this framework are under consideration, i.e., simultaneous comparison and sequential comparison. Only pulsed target illumination is considered, no development being undertaken on CW systems.

While both simultaneous and sequential comparison schemes are still actively under consideration, it was decided early in the program that concentration of initial effort on one was highly desirable. The motivating purpose was the amount of information which could be obtained only from field tests. Many of these tests could be performed on either system and would yield results of interest to both, as well as results necessary for progress in airframe and servo design.

In view of the history of successful field trials on BAT (an active sequential comparison scheme), it was felt that the system to be brought to the field test point first should be the sequential type.

The obvious difference between simultaneous and sequential comparison systems is that the former has the possibility of eliminating errors in directional information arising from fluctuations in the signal level during the scanning cycle and that the simultaneous system can furnish directional information more rapidly. These advantages are obtained at the expense of multiplying the number of receivers and involve the necessity of gain-balancing or phase-balancing these receivers. An obvious point for investigating then is the extent and rapidity of signal strength fluctuations encountered in typical tactical situations.

The first evidence bearing on this point was again the performance of BAT. While improvement over this performance is desired, it is reasonably good, and some of the departure from ideal must be attributed to other factors. Among these might be cited the variable position of the apparent center of radiation from the target[22], the lack of any provision for flying other than a pursuit course, and various other imperfections (in view of later developments) in the design. On the other hand, the fluctuation rate at the new frequency (X rather than S) was expected, from theoretical considerations[23], to be higher; and the proposed use of target error rate in some navigation systems puts a higher premium on smoothness of angular data than in the BAT system, where the angular data were not differentiated. (The process of differentiating a fluctuating signal emphasizes the fluctuation.)

Search of the literature and consultation with other laboratories produced no information of direct bearing on the question. Data on signal fluctuation in echo return from airplanes were available, but these were for smaller targets, the effect of the sea was not present, and the presence of the rotating propeller complicated matters. Consequently, an independent investigation was begun.

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With an X-Band transmitter and receiver, a series of runs was made on various sizes of ships at sea, from various aspects. The radar was carried in the nose of an airplane, which flew in at various glide angles over the range expected of a gliding missile and on low flat trajectories such as might be encountered with a powered missile. Information was recorded on the amplitude of each individual echo pulse.

In the first series of investigations, vertical polarization was used.[5] (Similar tests with horizontal polarization are contemplated.) Roughly, the conclusions were that the fluctuations are of considerable consequence at any scan rate and that they did not depend markedly on range or aspect. However, the effect is reduced by high scan rates.

The desired improvements over the BAT (pertinent to design of controls) are listed below:

(a) Increased probability of hit by

(i) Tighter tracking to avoid loss of target or change in targets,

(ii) Greater resolution in range and angle, for same purpose, and

(iii) Provision for computing interception course, obviating necessity of impossible rates of turn at end of trajectory.

(b) Increased range.

(c) Decreased volume and weight, and better aerodynamic properties in radome.

(d) Simplicity in use and maintenance; also producibility.

2. Characteristics of Selected System

Based on the above analysis and the desired improvements over the BAT intelligence system, the following over-all characteristics were selected for the first prototype for KINGFISHER.[8]

(a) System; sequential comparison[16]

(b) Antenna system; non-scanning transmitter with rapid conical scan on receiver; antenna stabilized and movable for computing purposes.

(c) R-f system; 1/4 microsecond pulse, 2,000 pulses/sec, 50 kw peak power; tunable magnetron (2J51).

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(d) **Receiver:** band width 5-6 mc/sec; 1/4 microsecond video gating with automatic tracking in range, and range velocity memory; electronic commutation of directional information.

(e) Primary power supply; 400-cycle generator driven (at constant speed) by variable pitch windmill (described in Sec. II-E).

In the following discussion, the lines of separation drawn above cannot be respected, due to the intimacy of the interaction between the various design factors. Enough has already been said of (a) to permit passing directly to the others.

(b) Antenna System

(i) R-f Properties

The system chosen for first tests consists of four horns; a complete assembly is shown in Figures 6 and 7. One horn points along the axis, one 7° up, one 7° down and 7° left, and the fourth 7° down and 7° right. The cross-overs in the radiation patterns are at about the half-power points. The horn that points along the axis is used for transmitting only. The other three are brought to a special switch section, where newly developed r-f switch tubes, gated electronically by the timing unit, permit use of the highest possible scan rate (a single scan cycle includes one pulse from each receiving horn). The signals from the two "down" horns are added (after the second detection, so no question of phase arises) for a true down signal to compare with that from the "up" horn; right-left information is also secured from the two down horns.

The gains of all horns are of the order of 110 (or 20.4 db) over an isotropic radiator. An additional effective gain of 3 db comes from use of an "on-course" rather than a scanning transmitter. A portion of this is lost again due to the use of three rather than four receiving horns, but space considerations are ruling here.

In addition, it is believed that a non-scanning transmitter will permit better streamlining of the radome. With a pointing dish and a scanning transmitter (as in BAT), any radome shape other than spherical can be expected to give a pulling effect on the magnetron, which varies exactly at scan frequency. The resultant variations in transmitter power and frequency would give rise to false directional information. This difficulty was met in the BAT and necessitated use of a hemispherical nose on the missile, which was aerodynamically unsatisfactory.

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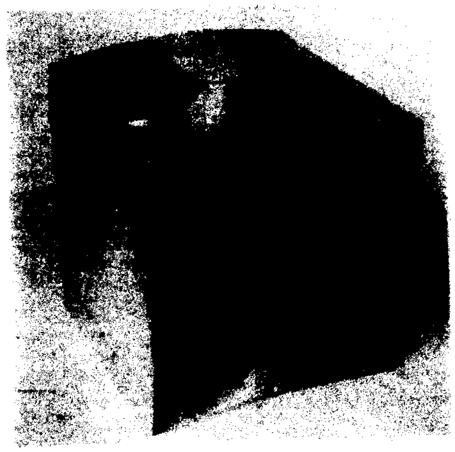
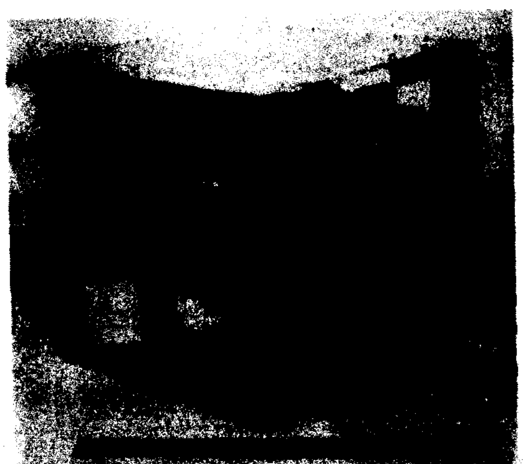


FIGURE 6 - FRONT VIEW OF HORNS OF ANTENNA SYSTEM FOR KINGFISHER



IGURE 7 - SIDE AND REAR VIEWS OF HORNS FOR ANTENNA SYSTEM FOR KINGFISHER
The transmitter is located in the space between the horns; the remaining space will be used by components of the antenna stabilization system.)

It is recognized that this antenna system suffers from the drawback of using only 1/4 the available antenna aperture at any one time. Nevertheless, its use will be advantageous in several particulars. Because of its simplicity and the feeble interaction between horns, construction and design were relatively easy, and thus a flyable homing head will be more quickly achieved. Second, design considerations indicate that this system can quickly be changed to a simultaneous amplitude comparison system for tests of the comparative merits of these two systems. (This antenna can hardly be converted into a satisfactory *phase* comparison antenna, however; due to phase relations arising from the physical separation of the antenna centers, reversal of directional information will be encountered with good signal strength at relatively small error angles.) *Third*, the space between horns is usable; in the present assembly, the magnetron, pulse transformer, local oscillator, signal crystal, switch section and r-f switch tubes, AFC crystal, and associated couplings are all mounted in this space, with some room left into which components of the antenna stabilizing mechanism can intrude.

Lack of switch tubes to the present has precluded measurement of the radar width of the system. Production of switch tubes of the type made by modifying 1B24 TR tubes has suffered several delays but is now beginning at a good rate and tubes are expected very shortly. Development of the new switch tube is being done at Sylvania under contract from the Naval Research Laboratory. A preproduction tube, designated *X-7047*, is shown in Figure 8.

The four-horn system, described above, would probably be too large for use in KINGFISHER Type B. An appreciable reduction in size appears most promising with common aperture systems, and these are being investigated. Interaction between the feeds of the common aperture is the most serious problem, and so far, good aperture illumination has not been achieved. A lens appears more suitable than a reflector because of the bulk of the feed system. Of various lenses considered, one of the Fresnel zone plate type showed considerable promise, primarily because of the high ratio of diameter to focal length. Such a lens may be seen in Figure 9. This lens has good optical properties and a focal length of only 4 inches. With such a lens, a rotating single feed could conceivably be used, but this would reintroduce the difficulties caused by scanning the transmitter and would, in addition, at high scan rates, introduce a range-dependent rotational shift. This arises because the maximum ranges envisaged give echo delays comparable to the interval between pulses. It is believed that the fluctuation data previously referred to indicate strongly in favor of high scan rate; and a high scan rate also favors tight tracking at maximum range due to the lower AGC time constant allowable. (There is a possibility also that it may reduce the requirements on the memory circuit for the same reason). It is felt that the problem of securing good aperture illumination with multiple feeds is soluble.

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FIGURE 8 - PREPRODUCTION MODEL OF SWITCH TUBE (X-7047)

FIGURE 9 - FRESNEL ZONE PLATE LENS
(A six-inch scale is at the bottom of the lens)

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In the existing antenna system, much efforts has been devoted to making the plumbing system of great band width so as to exploit the counter-countermeasure properties inherent in the tunable magnetron. The switch tube section was the most difficult item, but even here a broad design is believed to have been achieved. Actual measurements of width have been made only with approximations to the final tube, final production samples not having been received; however, it is believed that the system will be operable at least over the range from 3.2 to 3.5 cm. At present, a change over any large fraction of this range requires retuning of the mixer, local oscillator, and switch tubes, as well as the magnetron. However, broad-band switch tubes with no tuning adjustments required over the range 3.1 to 3.6 cm are under development elsewhere; a variety of wide-band local oscillator tubes are also under development elsewhere; and some work is being done here as well as elsewhere on the design of a broad-band mixer. A broad-band AFC transmitter coupling has already been devised.

(ii) Mechanical Properties; Stabilization

The antenna is to be mounted on a gimbal system so that computation may be done by rotating the radar axis relative to the line of flight. The radar axis is to be stabilized against pitch and yaw of the missile. Stabilization systems under investigation are discussed under servo development, Part D-1 of this report.

The weight of the first prototype antenna without the stabilizing mechanism, is about 28 pounds.

(c) R-f System; Modulator, Transmitter, and Mixer Units

The modulator is a conventional pulse-forming line, hydrogen thyratron and pulse transformer system. The new Alsifilm lines will probably be employed. Figure 10 shows the space saving which can be accomplished by the use of this dielectric. Both lines are 6E3, 1/4, 2,000, 50, the only difference being that the larger uses paper as a dielectric.

The thyratron in present use is a 1C35; however, development of a tube of smaller size is under consideration. The low duty cycle and possible reduction in life requirement should make a smaller size practicable.

The pulse transformer is mounted in a case containing also the magnetron socket, and both are placed in the space between the horns on the antenna assembly. Rotating joints in the r-f system and long magnetron leads are thus avoided.

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FIGURE 10

TWO ELECTRICALLY EQUIVALENT PULSE-FORMING LINES
(The one on the left is made of Alsifilm dielectric and the one on the right, with impregnated paper dielectric)

FIGURE 11

TWO I-F STRIPS FOR RADAR RECEIVING [illegible] FOR [illegible]
(The smaller model shown below gives an indication of the reduction in size possible with the use of [illegible] of the T-3 (subminiature) size.)

[redacted]

An unbalanced mixer of simplest type is at present in use, as first rough tests indicate a satisfactory noise figure can be obtained in this way. A special requirement is the need for a premixer AGC system to prevent crystal overload at short ranges. Data on preproduction samples indicate that the same type of tube used for the r-f switch can perform this function, the attenuation being variable from some 50 decibels smoothly down to about 10 decibels as the control electrode current is varied. At about 10 decibels, the arc goes out and the attenuation drops abruptly to the insertion loss of about 1 decibel. With a delay in the AGC applied to this electrode, this system can be used without detriment to performance at extreme range. There are beneficial by-products of the use of the premixer attenuator. The blanking requirements for close-range operation are greatly reduced (first measurement in fact indicating that this feature, combined with the shorter pulse length, may eliminate the necessity for supplying a blanking pulse). In addition, use of the attenuation in the receiving channels only, with full power maintained in the transmitting channel, is advantageous from the point of view of counter-countermeasures.

(d) Receiving and Data-Analysing Systems

A great deal of detailed development on receiving and data analysing systems has been described in reports already issued[10,13,15,18] or now in preparation. The necessity for such development arose from reduction in pulse length, requiring greater band widths and imposing more stringent requirements on tracking circuits; use of electronic rather than mechanical scanning; and use of a three-component rather than a four-quadrant scanning scheme.

In the i-f amplifier, a band width of only 1.5 τ, where τ is the pulse length, or about 6 mc, is used in order to economize on tubes and produce high signal-to-noise ratio. Fixed tuned staggered pairs are used and present experience indicates that it should be possible to wind all coils to mechanical specifications without electrical checking or tube selection. Use of more sophisticated schemes (double coupling, staggered triples or quartets, negative feedback) might save one stage, but at the expense of tuning adjustments. The present amplifier has none. Further, the "squarer" cutoff of these schemes would require a greater band width for equivalent pulse reproduction. The first three stages are gain-controlled by control-grid biasing; the time constant of the AGC (automatic gain control) circuit is tentatively set at 20 milliseconds, this low figure being possible because of the rapid scan. Computations indicate that the premixer attenuator may make possible the use of a fixed gain first stage, with some resultant benefit in noise figure; experiments in this direction are proceeding.

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A plate detector, operated at as low a level as will give reasonable linearity, is provided. No specific anti-jamming measures are included in the first prototype unit, such as back bias or instantaneous AGC; however, the low level detection gives excellent overload properties and thus gives good CW rejection. A video stage and cathode follower complete this unit; a moderate amount of fast time-constant is employed to reject the lower modulation frequencies without deterioration of pulse shape.

Experiments are being carried on also with smaller tubes as samples become available; Figure 11 shows the reduction in size achieved in an experimental i-f amplifier employing preproduction samples of pentodes in the T-3 (subminiature) size.

The automatic frequency control unit is conventional, operating by comparison of the transmitted and local oscillator frequencies, and controlling the latter through reflector voltage modulation. One relaxation oscillator causes the local oscillator to "hunt" for the transmitter. On crossing the proper frequency, signals from the discriminator fire a second thyratron, momentarily setting the hunt cycle back slightly. The hunt then resumes, is set back again, and the local oscillator "rocks" slightly around the proper frequency. An i-f amplifier similar to that in the main receiver is employed; and a conventional dual-diode discriminator. The use of thyratrons rather than the more common blocking oscillators eliminates the requirement for one or two pulse transformers. The hunt cycle is somewhat slower than is common in this type of control, since it is essential that the corrections to the frequency not be made at about three-pulse intervals, as is common, since this would give rise to a slight scan frequency modulation of the echo, which would be interpreted as directional information.

The video unit performs the following functions: (i) generates trigger for modulator and pre-triggers for other functions; (ii) generates gates for r-f switch tubes; (iii) generates range gate for selection of a single echo; (iv) transmits all echoes and position of range gate up to monitor in mother ship; (v) amplifies chosen echo for commutation of directional information; (vi) contains circuits required to lock gate on the chosen echo and track automatically in range (a range velocity memory is produced for cases of short interruption of signal); (vii) develops AGC voltage from gated echo only; (viii) generates gates in synchronism with (ii) for commutation of signal into appropriate differential amplifier; (ix) provides, from the differential amplifiers, output currents proportional to azimuth and pitch errors, for precession of gyro axis; and (x) contains two range switches for actuating torpedo release mechanisms.

Only a few general comments will be made. It is believed that an unusually economical switching and commutating system has been developed, and a detailed report concerning it is in preparation.

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The range gate tracking system required much attention since the requirements are approximately six times as stringent as in BAT. (The pulse length is narrower by a factor of 3 only, but the over-all width of the tracking gates is only one pulse width, due to the use of 1/3 microsecond tracking gates. In the BAT, 0.7-microsecond tracking gates were stacked edge to edge giving, with a 0 7-microsecond pulse, an over-all width twice the pulse width.) Consequently two systems were developed: one was a dual oscillator system[17] similar in principle to that used in the self-synchronous system in PELICAN; the second was a delay multi-vibrator system similar in principle to that employed in BAT (report in preparation). Both have been developed to a point of meeting bench tests; the multi-vibrator system, however employs fewer tubes. Part of this difference is in the counter-stages required to derive pulses at repetition rate intervals (approximately 2000 cps) from the stable crystal oscillators, running at present around 50 kc/sec. Development of lower frequency crystals or use of some other stabilizing unit, such as a magneto-striotive rod, might eliminate this difference. Those factors are being investigated.

Development of a new memory circuit makes possible longer memory.[15] An effort is being made to translate this advantage into a shorter learning time, so that maximum advantage may be derived from the memory circuit in tracking weak signals. The pointing antenna and the short AGC time constant should conspire to reduce the requirement for long memory times.

A new pulse-stretching system is being used to effect power amplification without producing "rotational shift" by carry-over of information from one receiving antenna to the next. A report describing the system is in preparation.

Standard type T-5 1/2 tubes are used throughout. Samples of several varieties of T-3 and T-2 tubes have been procured for experiments on miniaturization, with particular emphasis on reducing the size of the equipment so that it will be acceptable for KINGFISHER Type B. In addition, the possibility of using printed circuits in many parts of the electronic assembly is under consideration as a means of further reducing the size of the equipment.

D. SERVO SYSTEMS

1. Antenna Stabilization

It is desired that the antenna of KINGFISHER be stabilized against the pitch and yaw of the missile to within approximately 1/4 degree and without any oscillation. Since the servo system operating the bird controls may use antenna rate as well as antenna position, a dead-beat (non-hunting) system is considered essential. The maximum velocities required of the stabilizing system are expected to be of the order of 30°/sec. It would be desirable to have the antenna free to tip in any direction to an angle of 45° from the center line of the ship. However, the location of the

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suspension members may be such that these angles may be limited to 30°. Space limitations also complicate the realization of the stabilization requirements. Three methods of antenna stabilization are under investigation, and supporting development is under way at the Raymond Engineering Laboratories, the F. H. Shepard Laboratories, as well as at NBS.

In the first of these systems, two gyros are used. A large, heavy gyro has its axis fixed in the antenna, and serves as the primary stabilizing element and as a torque motor. This gyro will stabilize the antenna against jerks from the aircraft; however, torques due to connecting cables, unbalances, accelerations, etc., will cause slow precessions of its axis, and therefore of the antenna. These precessions will be detected by a second, truly free gyro mounted on the antenna. The information obtained from pick-offs on this gyro will be used to apply counter-torques to the gimbals of the antenna. When it is desired deliberately to precess the antenna for reasons of navigation, the free gyro axis is precessed to a new zero; the pick-off system will then force a corresponding precession of the main gyro. A schematic diagram of this system, labeled a "piggy back" stabilizer, is shown in Figure 12.

Since the free gyroscope is to be mounted on the antenna, it need not have more than 1° of freedom in any direction. This means that gyro gimbals are not needed and some type of a ball and socket or universal joint may be acceptable for the gyro support. Several such gyroscopes have been built and they show considerable promise. Two of these are shown in Figure 13. These gyroscopes are driven by a motor and use self-aligning bearings. The gyroscope wheels are driven by the friction of the bearing. This is sufficient to drive the larger wheel at 6,000 rpm when the motor is running at 8,000 rpm. Another possible answer for the free gyro is found in the Mark 18 gunsight. This sight has a universal joint gyroscope of a very light and compact construction. A photograph of the original and the modified gyroscopes is shown in Figure 14. The antenna direction will be controlled by precessing this free gyroscope while the large gyroscope will be controlled by pickup coils mounted near the free gyroscope wheel. These coils can be seen in Figure 14. Quantitative measurements on the inherent stability of the gyroscopes discussed are in progress but as yet incomplete.

Both the other systems use a single free gyro in the antenna and differ only in the servo system used to keep the antenna axis aligned with the gyro axis. Again, deliberate rotations of the antenna axis are accomplished by precessing the gyro axis; the servo thus having the single duty of keeping the antenna and gyro axes aligned. In one system, an arrangement of magnetic clutches operating from a continuously running motor gives proportional control; in the other, the clutches are replaced by a special differential gear system. The differential gear system is shown schematically in Figure 15, and a photograph of the first laboratory model is shown in Figure 16. Without anti-hunt features, this system held a mock-up antenna stable to within 1/4 degree with very little hunt. A complete model with anti-hunt features is under construction.

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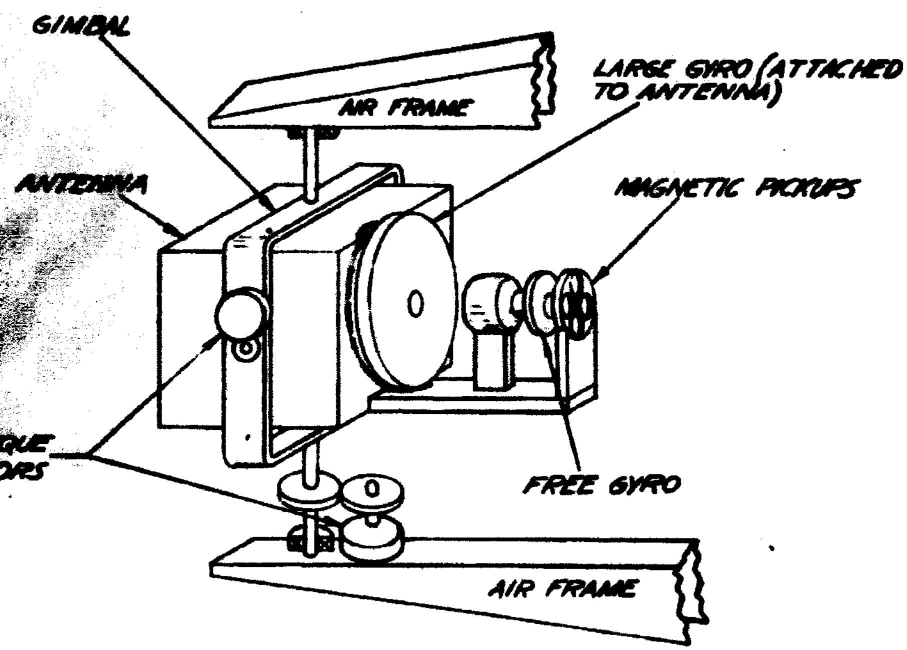

FIGURE 12

SCHEMATIC DIAGRAM OF ANTENNA STABILIZER SYSTEM USING A SMALL FREE GYRO AND A LARGE RIGIDLY ATTACHED (TO THE ANTENNA) GYRO

[redacted]

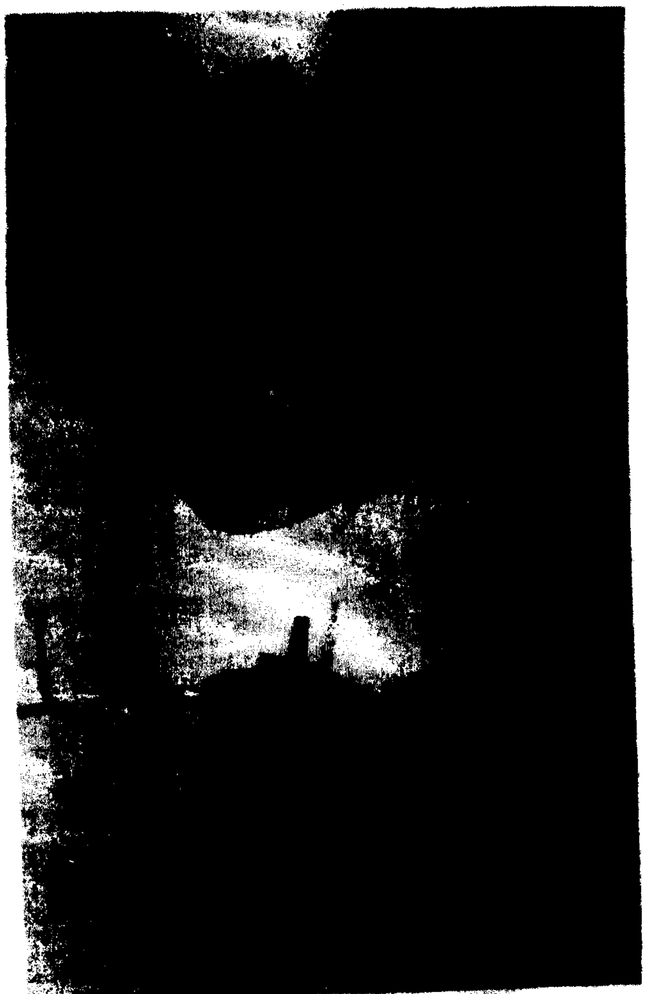

FIGURE 13

TWO GYROSCOPES DEVELOPED FOR CONSIDERATION AS THE FREE GYRO IN ANTENNA STABILIZING SYSTEM

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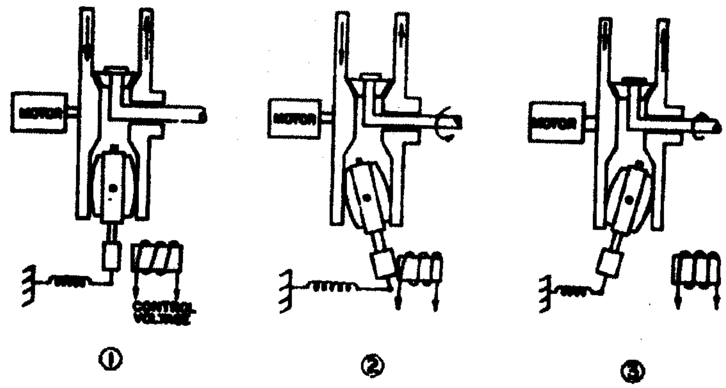

FIGURE 15

SCHEMATIC DRAWING OF THE DIFFERENTIAL GEAR-REVERSING CLUTCH FOR ANTENNA STABILIZER

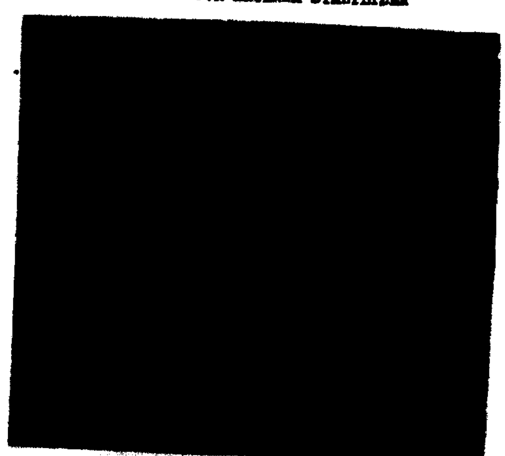

FIGURE 16

PHOTOGRAPH OF A DIFFERENTIAL GEAR SYSTEM SHOWN SCHEMATICALLY IN FIGURE 15

2. Main Control Servo

The requirements for the KINGFISHER control-surface servo have not as yet been fixed, and very little work has been done in this connection. Since the antenna will behave as a free gyroscope as far as yaw and pitch are concerned, it will be possible to use the antenna as a reference for the stabilization of missile as a whole. Because of the fact that the antenna axis and the ship axis may not coincide, an "axis resolver" may have to be used to provide a frame of reference for the missile. A separate free gyro can, of course, be used to obtain the same result.

The stabilization of roll can be obtained by using a roll gyroscope or a suitable angular accelerometer. Such accelerometers are commercially available, and a model specially designed for KINGFISHER is now being tested. This model is shown in Figure 17. It consists of a balanced member mounted on ball bearings and held in a fixed relationship to the frame by a spring. The natural frequency of the system is approximately 10 cps. Pick-off coils are mounted on both sides of this member so that an output voltage is varied both in phase and magnitude. This voltage can be employed through the control servo to counteract the roll of the ship. The advantage of the accelerometer over a gyroscope is the elimination of high-speed rotating systems and the need for driving power. An accelerometer should be much more foolproof and dependable than a gyroscope, to say nothing of being cheaper.

E. POWER SUPPLY

The primary source of energy, both for the radar and antenna stabilizing gear, and for the control-surface servos, is the airstream. Two generators, driven by one or two variable-pitch constant-speed windmills are to be used. The radar generator will supply approximately one kilowatt at 400 cycles, 117 volts; the servo generator will have a similar capacity, but the form of the output awaits further definition of servo requirements.

The variable-pitch windmill is a special design in which the power to rotate the blades is not derived from the speed-control network. Instead, the speed-control network operates a clutch which uses the power of the airstream itself to effect the rotation necessary for the indicated change of pitch. The principle is shown schematically in Figure 18. Wind tunnel tests on the first model, pictured in Figure 19, are very promising.

In addition to possible changes in type of primary supply desired, another reason exists for using separate radar and servo generators. The servo load may fluctuate quite sharply, and it is highly undesirable to have rapid fluctuation in radar supply voltage. However, generator inertia may be sufficient to permit mounting both on a common shaft and driving with a single windmill.

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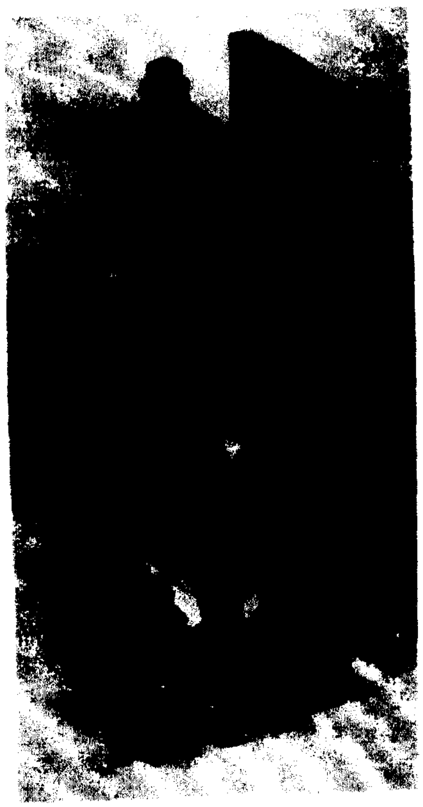

FIGURE 17

ANGULAR ACCELEROMETER UNDER CONSIDERATION
FOR USE IN MAIN CONTROL SERVO SYSTEM

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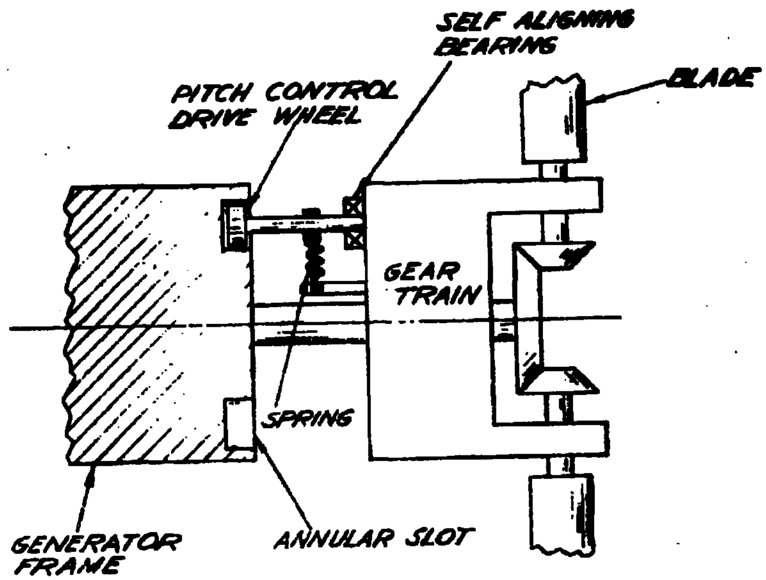

FIGURE 18

SCHEMATIC DIAGRAM SHOWING OPERATING PRINCIPLE OF AUTOMATIC PITCH CONTROL FOR WINDMILL OF KINGFISHER POWER SUPPLY

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FIGURE 19

AIR-DRIVEN POWER SUPPLY FOR KINGFISHER

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Design of the radar generator is well along. An 800-cycle model with a carbon pile regulator has been completed. This is shown schematically in Figure 20. Experiments on other regulation schemes, such as axial displacement of the rotor, and on alternative, possibly more compact, designs employing permanent magnet rotors, are in progress. The generator will not be larger than the invertor required in BAT to convert from battery power, thus making the space occupied by the batteries themselves pure profit. The air-driven generator increases drag on the missile about 1%.

Brakes will be supplied so that the generator need not run continuously throughout the time the bird is carried. This power supply will make it unnecessary ever to power to radar from the mother plane, thus simplifying the wiring in the umbilical cord.

The savings incident on eliminating the logistics problem associated with battery supply need hardly be mentioned.

F. FLIGHT SIMULATOR

A flight simulator has been developed and constructed for facilitating the development work on KINGFISHER. It is essentially a device for solving the equations of motion of the flight of a missile, and thus reproducing in the laboratory the behavior of missile in flight. A flight simulator provides a laboratory tool which is very useful in the appraisal of theoretical and practical flight control systems and should considerably reduce the amount of field testing required in the development of a suitable guidance and control system for KINGFISHER. Although designed as a tester for the KINGFISHER, the simulator has application to missiles of the same general type. A general description of the simulator is given in "The Guided Missile" for July 1946.

Figure 21 shows the platform on which the gyros or elements of the control system sensitive to angular motion are mounted. This platform is mounted in a gimbal frame free to rotate about three perpendicular axes. On the center of rotation is mounted an optical homing system to simulate the characteristics of the radar homing system of the missile. In this figure, the gyros of the S.ED Mark 9 Mod 0 BAT are shown on opposite sides and below the optical homing head.

Figure 22 shows, at the left, the light source used as a simulated target and which moves in such a manner as to represent the motion of the missile in space. In the center is the three-axis mounting which carries the platform shown in Figure 5. At the right is a control panel for adjusting the constants of the system to correspond to the aerodynamic characteristics of the missile under test.

Figure 23 gives another view of the general arrangement, showing the track along which the carriage moves to represent the approach of the missile to the target.

First tests on the simulator were conducted in October, and considerable time has been spent in making revisions which were found necessary from preliminary operations.

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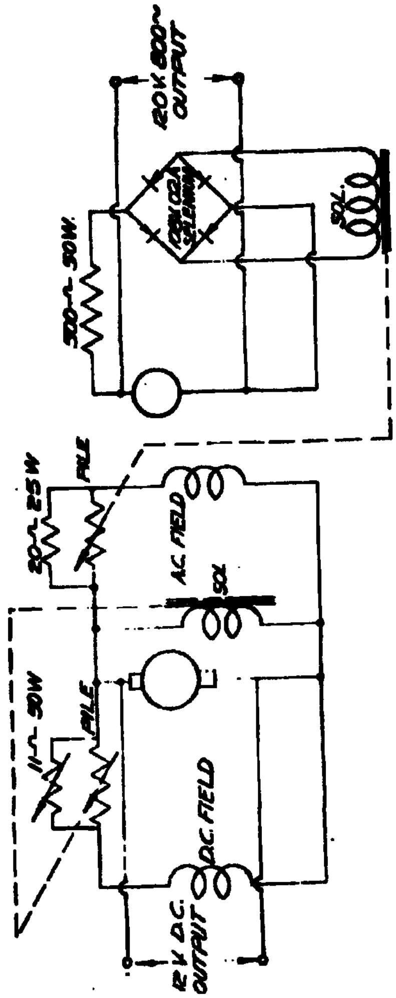

FIGURE 30 - CIRCUIT DIAGRAM OF POWER SUPPLY FOR RADAR SYSTEM OF KINGFISHER

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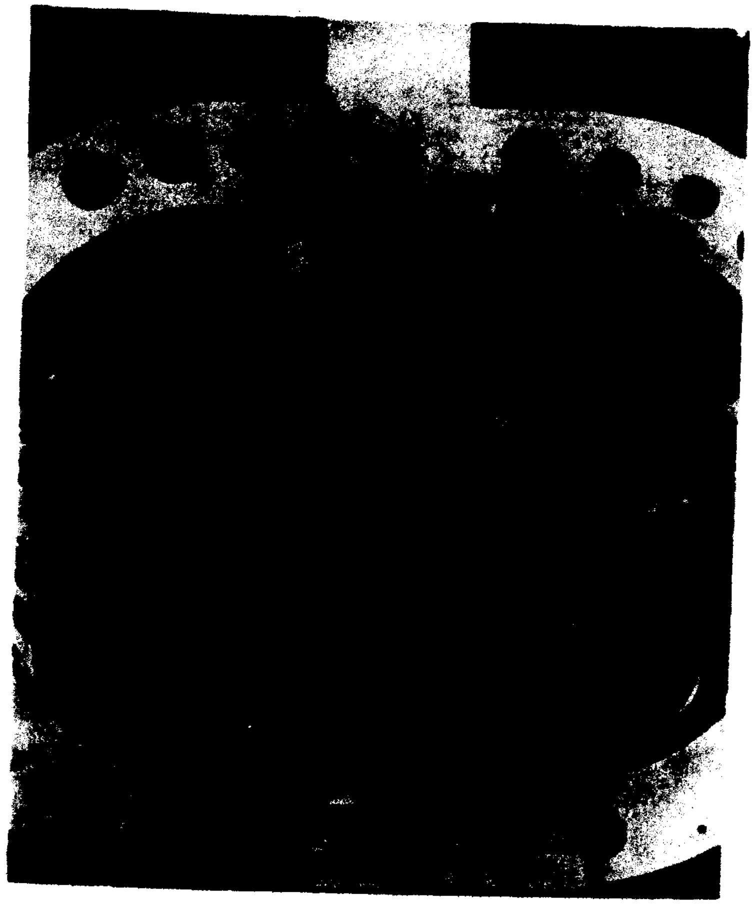

FIGURE 41

PLATFORM OF FLIGHT SIMULATOR ON WHICH THE GYROS (OR ELEMENTS OF CONTROL SYSTEM SENSITIVE TO ANGULAR MOTION) ARE MOUNTED

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FIGURE 22 - GENERAL VIEW OF FLIGHT SIMULATOR
On the left is the light source used to represent the target, in the center is the platform shown in Figure 21, and on the right, the control panel.

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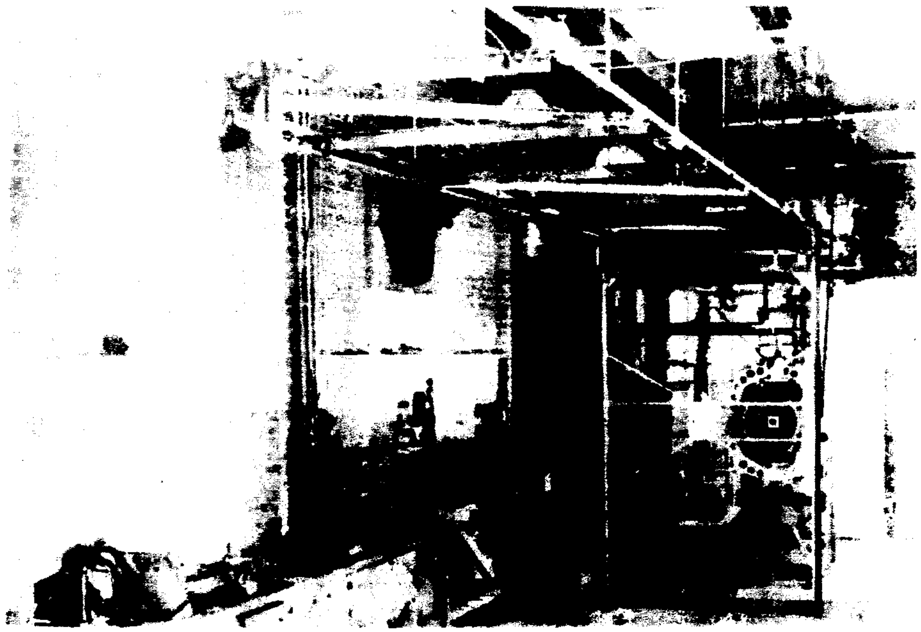

FIGURE 23

ANOTHER GENERAL VIEW OF THE FLIGHT SIMULATOR SHOWING THE TRACK ALONG WHICH THE LIGHT SOURCE MOVES TO REPRESENT APPROACH OF THE MISSILE TO TARGET

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The following investigations are now in progress using the flight simulator:

(1) Comparison of the control systems of the Mod 0 and the Mod 1 BAT with respect to accuracy of the missile under varying wind conditions.

(2) The investigation of the effects of squints in the gyro system, servo system, and homing on the accuracy of the missile.

(3) The investigation of the performance of proposed navigation systems for KINGFISHER.

Under Item (1), 29 runs have been taken with the control system of the Mod 0 BAT, with wind set for 40 mph right, 29 runs with wind 40 mph left, and 40 runs with no wind. The average deviation varies from 34 feet to 80 feet. The distribution of error does not follow a normal probability distribution due to a small long-period oscillation in yaw evident in these runs. The results are in excellent agreement with actual field tests of Mod 0 BAT, thus demonstrating that with the simulator, performance of the navigation system of a missile can be predicted under various flight conditions.

F. INSTRUMENTATION

The instrumentation system for KINGFISHER is intended to provide data on the performance of the missile and its components while in flight. The flight tests referred to above (under II-A and II-B) have used the instrumentation system developed for BAT. This system includes two recording cameras within the missile and two ground stations for obtaining trajectory data by optic methods. The cameras within the missile are enclosed in rugged cases to preserve the records from damage caused by impact of the missile. One camera photographs an instrument panel and the other, the view directly ahead of the missile. In some cases, a third camera has been added to photograph an oscillograph connected to the intelligence system.

Appreciable work has been done toward improving the BAT instrumentation system, including better synchronization of the airborne cameras, more reliable erectors for the lenses and mirrors, and installation of Askania recording theodolites in the ground stations. In addition, serious attention is being directed toward developing or adapting telemetering systems and radar plotting methods. The telemetering system will supplement rather than replace the recording cameras.

A pulse-time telemetering system has been developed which requires only one tube per channel. It also allows considerable flexibility in scan rate and in the number of channels. The full possibilities of the system are still being investigated. However, in view of the fact that most of the testing of complete KINGFISHER missiles will be at NAOTS Chincoteague, where other guided missiles are also to be tested (notably DOVE and METEOR),

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the possibility of using a standard system is under consideration. If the same or similar telemetering systems are used in all tests, the ground installations at the station would be appreciably simplified. Similar standardization would be desirable, if possible, for trajectory plotting instrumentation.

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3. Monthly Progress Report for August, September and October 1946, by National Bureau of Standards, pertaining to work on Project KINGFISHER.

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NBS NUMBERED REPORTS AND MEMORANDA

5. OD-6-18R, June 20, 1946, "Fluctuation in Amplitude of Echo Return from Seaborne Targets: I - Vertical Polarization."

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19. CD-1-27M, July 11, 1946, "Technical Memorandum on Memory Circuit Tester."

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22. OSRD Report No. 6413, November 30, 1945, Final Report on Development in Radar Homing Missiles, by P. R. Stout, D. L. Huth and H. F. Huntsman, "Apparent Radiation Center of Ship Targets as Seen by Conically Scanning Direction Finding Radars Used in Homing Missiles."

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ABSTRACT:

Progress of the Kingfisher project is summarized from the date the program was initiated until December, 1946. Project Kingfisher is engaged in the development of a radar-controlled, subsonic, self-homing, air-launched missile capable of delivering an explosive charge below the waterline against floating targets. Photographs of the Kingfisher and its equipment are shown.

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