PROGRESS REPORT NO. 11
PROJECT NO. 124-27
CONTRACT NO. NORD 10020

TASK A - ANALYSIS OF FIRING ERRORS

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By
J. E. BOYD
and
W. J. MILLER

MAY 31, 1966
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I. SUMMARY

During May, 1948, experimental work on Task A of Contract NOrd 10020 was completed, but some analytical work remains to be finished. In the analysis of data from the St. Joseph's Spit firings, the process of tabulating distance measurements taken from the film records was completed. Analysis of the high-speed motion pictures from the firings at Dahlgren was begun, and good progress was made.

Task B radar scanner studies were continued, a microwave laboratory was equipped and placed in service, and some significant photographic experimental work directed toward the optimum method of data recording was carried out. Considerable circuit design and construction went forward.

Task C experimental work continued at the Navy Mine Countermeasures Station, Panama City, Florida, with the usual fine cooperation from station personnel, and numerous data were recorded.

There was no significant progress on Task D during May.

The final report on Task A will be prepared during the month of June, 1948.
II. INTRODUCTION

The general objectives of research and development to be performed under Contract NOrd 10020 are as follows:

Task A: Theoretical and Experimental Study of the Requirements for Rapid and Accurate Analysis of Firing Errors.

Task B: Modifications of Existing Equipment and/or Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of the Order of Magnitude of 5000 sq. cm. of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments Including Possible Minor Modification of Such Equipment to Determine Their Potentialities for Effective Tracking of Small Surface Targets.
A. Task A—Analysis of Firing Errors.


During the month of May, 1948, the routine work of measuring and tabulating data from the films obtained during the firings off St. Joseph's Spit, Florida, was completed. The firings and the methods of removing information from the photographic recordings have been described in previous progress reports. The data taken from the films consist of frame-by-frame values of the range and bearing of the splashes relative to the target buoy position (or relative to range and bearing reference lines when the blip from the target buoy was not available), and the values of the dimensions of the splash blips in range and azimuth. The derived data will permit a study of:

(a) The locations and average dimensions of splash blips resulting from one, two, or three projectiles falling close together.

(b) The percentage of merged splash blips occurring in forty salvos.

(c) The percentage of individual splashes which can be located from the photographic recordings.
(d) The growth of the splash blips on the indicator scope,

(e) The length of time of observation necessary to identify and locate splashes.

(f) The frequency of appearance of radar indications from projectiles before they have landed.

(g) The sizes of blips from projectiles in the air.

The data are being further subdivided for study into categories determined by the ranges at which the projectiles were fired and by the types of projectiles used. A critical comparison is being made between the results obtained with the Fairchild Type A Recording Camera and the AN/TPQ-2 B-Scope and those obtained with the Dumont Type 314 Oscillograph-Record Camera and the Auxiliary scope. There is a great deal of work remaining to be done before these data will be completely reduced and reliable conclusions drawn from them with regard to all the items listed above.

2. Dahlgren High-Speed Motion Pictures.

High-speed motion picture films of 5-inch, 6-inch, 8-inch, and 16-inch projectile splashes were received from the Naval Proving Ground, Dahlgren, Virginia, during the month of May, and the analysis of these films was begun immediately. The pictures are being studied
frame by frame to determine the changes in shape and dimensions of the splashes as a function of time after projectile impact, the directions of growth in width, maximum heights and widths, and other factors, including sizes and shapes as a function of firing range and projectile size. It is believed that these films will yield the best information available to date on the above items of interest in connection with a firing analysis radar. Analysis of the data from the Dahlgren firings should be completed in June.

3. Additional Tests at Navy Mine Countermeasures Station, Panama City.

In order to obtain further information on the relationship between the actual target and its presentation on scope photographs, the following two test series were performed by the field group at the Navy Mine Countermeasures Station during May:

(a) Individual pulse shapes were recorded for the K-band signal generator output, the range marker, the transmitted pulse, and the return signal from a standard target.

(b) A pair of Mark IV mine cases were observed and photographed on the AN/TPQ-2 B-scope indicator for distances of separation varying between 15 and 75 yards and with the two mine cases making angles of
90° and 150° with the radar line of sight.

The data furnished by these tests will be used as an aid in the interpretation of the splash blip data obtained in the St. Joseph's Spit firings.

B. Task B--Firing Error Analysis Radar.

Scanner and system design studies were continued during the month of May. Several modifications of the circuitry of the AN/TPQ-2 have been initiated to improve its performance or to adapt it better to the needs of firing error observation. An additional laboratory room has been made available to the project, and it has been rearranged and equipped for microwave component design and test work. Some experimental photographic work was carried out at Panama City with the object of improving photographic recording methods and determining circuit features which will be necessary to obtain satisfactory photographic records with the firing error analysis radar.

1. Scanner Design Studies.

The scanner design group has concentrated on the rotating antenna approach to the wide-angle scanner problem. Present thinking indicates that three reflectors will be used. It is probable that the reflectors will be formed by taking sections from the surface of an elliptical cone, since this procedure will permit mount-
ing the necessary feed so that it will not interfere with the re-
flected pattern. This design has proceeded to the stage where a
pasteboard scaled-down model of the three reflecting surfaces has
been built and a three-way microwave switching element has been de-
signed and tested in the new laboratory. The tests indicated that
some additional work would have to be done to improve the standing
wave ratio of the microwave switch, and this work is in progress.

In equipping the microwave laboratory, several items of test
equipment were designed and constructed by the antenna design group.
These are listed and briefly described below and are illustrated in
Figures 1 and 2.

(a) A power supply and square-wave modulator unit for
the 2K50 klystron was designed so that the klystron can
be modulated at 10 kilocycles to give a K-band test signal.
This unit can also be used to drive a 723A or 723B X-band
klystron. It is shown in Figure 1 mounted in the lower
half of the panel and rack arrangement to the right of the
center of the picture.

(b) A power supply and square-wave modulator unit was also
designed to drive a 2K33 klystron, giving the requisite
slightly higher power at the same modulation frequency as
the 2K50 modulator—10 kilocycles. This unit is shown at
the left in Figure 1.
Figure 1.

Microwave Test Equipment.
(c) A tuned 10-kilocycle amplifier was designed and constructed with a built-in vacuum-tube voltmeter. This amplifier gives a voltage gain of about one million and has a bandwidth of approximately 200 cycles between the half-power points.

(d) A K-band slotted section with the necessary probe and precision adjustments was designed by the antenna group and constructed in the station machine shop. A dial gauge is used to indicate position directly in millimeters. The unit is shown connected in a typical test set in Figure 1, and a more detailed view is given in Figure 2. A slot resonance effect causes a slight error in indicated standing wave ratio. A new block which is expected to reduce this effect is now under construction.

(e) A flap attenuator and a low-power tapered waveguide termination were also constructed and found to have good microwave characteristics. These units are also shown in Figure 1. The flap attenuator appears just in front of the right-hand edge of the amplifier-modulator panel, and the termination may be seen projecting from the flange at the left end of the waveguide assembly.

(f) A 2K33 klystron oscillator cavity which was built in the station shops may be seen at the extreme left in Figure 1. The only unit which was not designed and constructed by project
Figure 2.
K-band Slotted Section.
personnel is a precision attenuator located at the approximate center of the wave guide line in Figure 1.

2. System Design Studies.

Over-all system design studies are continuing, but there is little significant progress to report for the month of May. The tentative functional block diagram which was mentioned in the April Progress Report has been photostatted and is shown as Figure 3. Present thinking continues to point toward a modified AN/TPQ-2 system with a wide-angle scanner and the best photographic method of data-recording which can be provided.

3. Circuit Component Design.

Several circuit components designed either to improve the AN/TPQ-2 performance or to provide features which experience has shown will be necessary in the firing error analysis radar have been undertaken.

(a) An oscillator-divider unit to replace the similar unit in the AN/TPQ-2 system has been designed and constructed. This unit will provide stable repetition rate trigger pulses with a frequency of 163.8 kilocycles and a choice of division ratios of 20:1, 25:1, and 30:1 available on the front panel. Additional ratios can be provided by an adjustment which is
Figure 3. Tentative Functional Block Diagram for a Firing Error Analysis Rader.
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made on the rear panel of the unit. The new oscillator-divider has been sent to Panama City to replace the unsatisfactory unit in the AN/TPQ-2 now in service at the Navy Mine Countermeasures Station.

(b) A modification has been designed and inserted in the spare AN/TPQ-2 range unit which will permit the use of 500-yard range markers instead of the 1000-yard markers originally provided in the AN/TPQ-2. The unit contains a provision for using a single marker when it is desired to read an accurate range from the radar to a single target.

(c) An effort is being made to develop sharper images on the radar indicator scopes by means of received pulse sharpening techniques. Various schemes involving non-linear amplification have been tried, but complete success has not yet been achieved. However, this work shows promise and will be continued.

(d) A pulse generator for use in test work in the radar circuits laboratory has been designed and constructed. This instrument is extremely flexible and will permit radar pulse simulation for test and experimental development work. The pulse generator is capable of producing wide ranges of variation in pulse length, repetition period, pulse delay, and
output voltage. An improved model is already under construction since it will be desirable to have several of these generators as the circuit development work progresses.

4. **Task B Photographic Experiments.**

Experimental studies were conducted during May at the test site at the Navy Mine Countermeasures Station with a view to determining the best photographic methods of recording cathode ray oscilloscope patterns for use in the firing error analysis radar. The Dumont Type 314 Oscillograph Record Camera was adapted to the AN/TPQ-2 B-Scope for these studies. The arrangement of the camera and indicator is shown in Figure 4. The relationships between various voltages in the indicator system and the photograph image density for several film types were studied. Variations in the film developer solution and in the method of processing were introduced. Signal voltages at the cathode of the scope were plotted for various signal strengths and receiver gain settings to determine the range of video voltages to be expected in practice. Pulse shapes were also studied. The technique employed in consideration of these numerous variables is to study one of them at a time, holding other values constant. The results of these studies have not been evaluated yet, but it is believed that they will permit arrival at optimum indicator-voltage
Figure 4.
Dumont 314 Camera on AN/TPQ-2 Indicator.
and photographic-variable combinations. More work of this type will be carried on at the laboratory at Georgia Tech.

C. Task C--Reflecting Properties of Small Surface Targets.

The making of signal measurements and of comparisons on the returns from small objects projecting from the surface of the water continued during May at the Navy Mine Countermeasures Station, Panama City, Florida. These tests have been described in previous reports and will not be discussed in great detail here. Most of the data taken during May were concerned with studies of the radar reflections from cylinders projecting out of the water at various angles of tilt from the vertical and at various angles of orientation from the direction of the radar. The work has been expedited considerably by the use of an ingenious mount for the cylinders, which was reported previously, but which is illustrated for the first time in the project report series in Figure 5. The problem of mounting and moving the targets in the desired manner, while holding them rigidly to prevent variable reflections due to the action of wind and water upon the target and its mount, has given the field group considerable trouble. The target mount illustrated in Figure 5 appears to solve the difficulty fairly well and, at the same time, permits the angle of orientation to be varied from a remote-control position on the shore.
Figure 5.
Adjustable Radar Target Mount.

Tilt and orientation studies with both the 6-inch and 2-inch cylinders for a range of 1000 yards and an antenna height of approximately 22 feet above water have been completed. The results have been plotted and are in the process of analysis and comparison with theoretical values. Some of the results are in fairly good agreement with theory, but there are a good many unexplained departures from the expected values. The analysis continues, and the collection of additional data will proceed as rapidly as possible.

2. X-Band Reflection Studies.

Experimental work at X-band, using the makeshift X-band radar and taking readings simultaneously with the K-band radar, has been going on intermittently during the month of May. The operational difficulties experienced with the X-band radar have seriously limited the amount of data accumulated for this frequency. Some of the results indicate fair agreement with theory, but it is too early to arrive at a definite conclusion. It does appear that K-band is superior to X-band for the small-object reflection work at short ranges.

3. Meteorological Data.

The recording of meteorological data while the radar measurements are in progress has continued during May. As yet no significant correlation between the meteorological conditions and propagation...
anomalies has been evidenced. The present practice will be maintained to insure that no opportunity is missed for obtaining new correlations between anomalous propagation and meteorological conditions.

D. Task D--Small Surface Target Tracking Equipment.

Due to the concentration of effort on Tasks A, B, and C no significant progress was made on Task D during May. However, the possibilities of utilizing the present radar site and equipment at the Navy Mine Countermeasures Station in the task of tracking small targets to ranges of 8000 or 10,000 yards (in St. Andrews Bay) are being considered. Signal-strength versus range data could be obtained on small boats, and possibly on small targets towed by a boat at a distance sufficient to provide separate (or resolved) radar signals. It is expected that tests of this type will be started during July.

E. Personnel Changes.

Additional personnel have already been hired to begin work during the month of June, when they will be needed to accelerate development work under Task B. Information on these future employees will be furnished in the progress report for June, 1948.

1. Personnel Additions.

The following personnel were added to the project staff during the month of May:
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<th>Title and Duties</th>
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<tr>
<td>Edward R. Flynt</td>
<td>Research Assistant (Member of Field Research Unit)</td>
</tr>
<tr>
<td>Nelson A. Logan</td>
<td>Research Assistant</td>
</tr>
<tr>
<td>Donald LeRoy Chase</td>
<td>Technical Assistant (Part-time Analyst)</td>
</tr>
<tr>
<td>George W. D. Cook</td>
<td>Engineering Draftsman</td>
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Donald LeRoy Chase: Senior in M. E. at Ga. Tech.; experience in research and engineering at Southern Belting Co., Atlanta, Ga., before entering Navy.

George W. D. Cook: Two years of "Machine Tool Design" at Ga. Tech.; two years' experience in optical fire-control instrument repair for Army Ordnance Dept. (Augusta, Ga.); three years' experience with Pan Electronic Laboratories (Atlanta, Ga.) manufacturing quartz crystal oscillators.

2. Personnel Losses.

The following personnel terminated employment on the project during May:

C. E. Durkee
S. C. Barnett
IV. OUTLINE OF WORK FOR JUNE

1. Continuation of scanner design studies.
2. Initiation of physical construction of rotating scanner, if possible.
3. Continuation of system design studies.
4. Continuation of design and construction of system and circuit components for use in the firing error analysis radar.
5. Continuation of measurements of overwater reflections from small surface targets at the Navy Mine Countermeasures Station, Panama City, Florida.
6. Completion of analysis of splash photographs from the Naval Proving Ground, Dahlgren, Virginia.
7. Completion of analysis of data obtained in St. Joseph's Spit firings.
8. Preparation of final report on Task A.

Respectfully submitted,

J. E. Boyd,
Project Director

Approved:

W. J. Miller,
Project Administrator

Gerald A. Rosselot,
Director
PROGRESS REPORT NO. 12
PROJECT NO. 124-27
CONTRACT NO. NORD 10200

TASK A - ANALYSIS OF FIRING ERRORS
TASK B - FIRING ERROR ANALYSIS Radar
TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS
AND
TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By
J. E. BOYD

JULY 31, 1948

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PROGRESS REPORT NO. 12
PROJECT NO. 121-27
CONTRACT NO. NORD 10020

TASK A - ANALYSIS OF FIRING ERRORS

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD

JULY 31, 1948

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I. SUMMARY

During the months of June and July, 1948, work on Task A of Contract NOord 10020 was completed, and the final report on Task A was prepared and submitted as Technical Report No. 4, "Radar Analysis of Surface Firing Errors."

Design studies and laboratory work on Task B, directed toward development of an experimental model of a firing error radar system, were continued. Plans were drawn up for the assembly of an integrated firing error analysis system to consist of modified and repackaged components of the AN/TPQ-2, a new wide-angle scanner, photographic-recording indicators, computers, and other components. Considerable progress was made in the construction and laboratory testing of experimental components of the proposed firing error radar system.

Experimental work under Task C at the Navy Mine Countermeasures Station, Panama City, Florida, was completed for the target range of 1000 yards, and measurements began at a new range of 2300 yards. Improvements in measuring equipment and techniques should result in completion of the series of tests under Task C in the near future.
II. INTRODUCTION

The general objectives of research and development to be performed under Contract NOORD 10020 are as follows:

Task A: Theoretical and Experimental Study of the Requirements for Rapid and Accurate Analysis of Firing Errors.

Task B: Modifications of Existing Equipment and/or Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of the Order of Magnitude of 5000 sq. cm. of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments Including Possible Minor Modification of Such Equipment to Determine their Potentialities for Effective Tracking of Small Surface Targets.

The final report on Task A, Technical Report No. 4, "Radar Analysis of Surface Firing Errors," contains a detailed description of all work performed in connection with Task A. Although the principal results of the analysis of the Naval Proving Ground, Dahlgren, high-speed motion-picture photographs of shell splashes,
and of the Port St. Joe scope photographs of radar indications from 5-inch shell splashes are presented in Technical Report No. 4, it is planned to submit more complete analyses of these photographic data in another technical report. It is considered that a more complete discussion of splash characteristics, may prove of value to others who are engaged in ballistic studies. Further analysis of the scope photographic data should also contribute information of value in connection with Task B design studies.

Present planning of work on the remaining tasks of Contract NOrd 10020 calls for concentration of major effort on Task B. An attempt will be made to assemble a complete experimental model of a firing error radar system, including a new wide-angle rapid scanner, photographic-recording indicator, and computer, not later than the end of 1948, in order that the system may be tested under simulated firing practice conditions during the early months of 1949. Fulfillment of this schedule depends largely upon antenna development, which presents by far the most difficult problem of design and construction.

Experimental work on Task C at the Navy Mine Countermeasures Station, Panama City, Florida, is being expedited with a view toward completion of all tests on or about 20 September 1948. Results
will then be analyzed and a technical report prepared.

Future plans for work at the Navy Mine Countermeasures Station include AN/TPQ-2 radar measurements of echo strengths from small towed targets in St. Andrew's Bay. These tests should contribute to Task D, since they will provide limited information on the potential tracking capabilities of a narrow-beam, short-pulse radar. It is planned to record echo strengths photographically.
A. Task A—Analysis of Firing Errors.

Experimental work on Task A was completed several months ago, but analysis of scope photographs from the Port St. Joe firing tests and of splash photographs from the Naval Proving Ground, Dahlgren, Virginia, continued into June, 1948. Upon completion of the analysis of the photographic data, preparation of the final report on Task A began in June. Processing of the report was completed, and ten copies are being forwarded to the Bureau of Ordnance. This final report on Task A was submitted as Technical Report No. 4, entitled "Radar Analysis of Surface Firing Errors."

Technical Report No. 4 describes thoroughly all work performed under Task A, including: (a) studies of operational requirements for observation of fall of shot, (b) studies of the desirable characteristics of a firing error radar, (c) experimental tests of the capabilities of the AN/TPQ-2 radar, (d) experimental studies of photographic methods for rapid recording of radar data, (e) analysis of firing data and splash characteristics, (f) analysis of radar indications of shell splashes, (g) studies directed toward the design of a firing error radar system with a wide-angle rapid scanner. Conclusions and recommendations for the development of an experimental model of a
firing error radar system are also presented.

B. Task B—Firing Error Analysis Radar.

Radar system design studies, antenna developments, construction and test of radar components, and experimental studies of photographic methods of recording scope presentations were continued during the months of June and July, 1948. Plans were drawn up for the assembly of a complete firing error radar system, consisting of modified units from the AN/TPQ-2 radar, a new antenna system, photographic-recording equipment, and computers. A new cabling and packaging plan will simplify operation and maintenance and will greatly facilitate troubleshooting.


A functional block diagram of the proposed experimental model of the firing error radar system, as it was visualized in June, 1948, was presented in Technical Report No. 4. The functional block diagram is now being revised to incorporate changes resulting from recent design studies under Task B. The firing error radar system will consist of three major unit-groups: the Control and Indicator Console, the Photographic-Recording Indicator, and the Antenna Assembly (including the scanner, RF unit, modulator, and junction box).
(a) Control and Indicator Console.

Plans have been drawn up for a control and indicator console unit, which will combine the AN/TPQ-2 indicator with the control unit shown in the functional block diagram of June 15, 1948. The console is being designed with special attention to ease of operation, maintenance, and troubleshooting. Controls for operation and adjustment of the radar are conveniently arranged, within easy reach of the seated operator. Recessed screwdriver adjustments will be made available from the front panel of the console to facilitate calibrations and adjustments which are made occasionally—such as range unit, movable azimuth-marker circuit, servo amplifier, and AGC adjustments. Provision is being made for mounting the Fairchild Record Camera on the AN/TPQ-2 B-scope in the console. An experimental scale model of the console is now being constructed.

(b) Photographic-Recording Indicator.

The photographic-recording indicator, less video circuits, has been constructed. This indicator is designed for use in recording splash-blip data with the DuMont Type 314 Oscillograph-Record Camera by means of the continuously moving film technique. Experiments to determine optimum
scope settings and photographic methods for recording oscillograph data will begin in the near future; laboratory pulse-generators will be used as sources of time base and signal pulses, in conjunction with the photographic-recording indicator.

(c) **RF-Unit Modifications and Tests.**

The on-off type of automatic gain control (AGC), which is to be tried out as a means of reducing the dynamic distortion of radar splash blips, has been designed on paper. Construction of a bread-board model of this AGC system will begin shortly.

The intermediate frequency (IF) response characteristics of the AN/TPQ-2 receiver have been measured. For receiver gains of 63 decibels or lower the band width was found to be 9 megacycles per second at the level of 3 decibels down (below peak) and 11 megacycles per second at 6 decibels down. For higher gain levels the band width is less. For a receiver gain of 81 decibels the band width at 6 decibels down is only 5 megacycles per second. It was found that the band width did not vary appreciably with crystal current (as determined by local oscillator power output) if the crystal current was held within the limits
recommended. This information will be of value in connection with proposed changes in video design to improve the over-all response characteristics of the receiver.

2. Antenna Design and Development.

Design and construction of experimental K-band components for a rotating-antenna system which will provide a rapid scan over a sector of about 90 degrees, continued during June and July, 1948. The antenna system will utilize three reflectors in an equilateral-triangular arrangement (spacing of 120 degrees between beam axes). As the antenna rotates, the reflectors will be energized one at a time, and in sequence, over the desired scan sector, by means of a three-way microwave switch. Thus, three scans per revolution will be provided, with the scan angle appreciably less than 120 degrees, since there will be no transmission during the switching interval. Rotation of the antenna system at a rate of 200 rpm will provide 10 scans per second over an angle of about 90 degrees. An artist's conception of this antenna system was presented in Technical Report No. 4.

A number of experimental components of the microwave equipment needed in connection with development of the scanner system were constructed during June and July. Brief descriptions of the more important developments follow.
(a) Elliptical-Cone Reflector.

An experimental model of the elliptical-cone type of reflector which is planned for the scanner system is shown in Figure 1. This model is intended primarily for determination of the beam pattern of the elliptical-cone reflector and pill-box feed. Other equipment needed for the pattern tests is nearing completion. In a preliminary test of the reflector, the sun's rays were focused to a line about one-fourth inch wide, indicating that the surface is probably true enough for practical purposes.

(b) Auxiliary Equipment for Reflector Tests.

A parabolic reflector, with a tripod support, has been constructed for use as a receiving antenna in making beam pattern measurements for the elliptical-cone reflector. A rotatable table is being constructed to serve as a mount for the elliptical-cone reflector in the pattern tests. A linear phase detector for laboratory checks of both the pill-box and the reflector is nearing completion.

(c) Phase Shifter.

A K-band phase shifter which was constructed for use in phase measurements is shown in Figure 2. The phase shifter consists of a section of K-band wave guide with a
Figure 1. Preliminary Model of an Elliptical-Cone Reflector for the Experimental K-Band Rotating Antenna.
Figure 2. Phase-Shifting Device for K-Band Phase Measurements.
slot one-sixteenth inch wide in the top. A strip of polystyrene is inserted in the guide by micrometer adjustment. The phase shifter has been tested and calibrated and seems satisfactory.

(d) Circular Phase Detector.

A circular phase detector which was constructed for use in phase measurements is shown on the right-hand portion of Figure 3, in a laboratory setup for testing a pillbox feed. A klystron source and the phase shifter described above may be seen to the extreme left and left center, respectively, of Figure 3. It should be noted that three rotating joints are used to facilitate changing the radius of the pick-up. It is also possible to move the feed which is under test with respect to the center of rotation.

(e) RF Switch.

A stationary model of an RF switch, which is being used to obtain design data to aid in the construction of the final rotating model, is shown in Figure 4. The two micrometer heads are used to move short circuits inside the switch, and the crystal mount is used to check the purity of the microwave frequency mode.
Figure 3. Circular Phase Detector for K-Band Phase Measurements.
Figure 4. Three-Way RF Switch for Experimental K-Band Rotating Antenna.
3. **Photographic-Recording Studies.**

Provisions are being made for mounting the DuMont Type 314 Oscillograph-Record Camera on the photographic-recording indicator and the Fairchild Type A Record Camera on the AN/TPQ-2 B-scope, in the experimental model of the firing error radar now being developed under Task B. Analysis of the film records of splash blip data obtained by the two photographic methods in the Port St. Joe firings did not provide adequate information for making a final choice between the two types of photographic recordings. The auxiliary indicator used with the DuMont camera was developed hurriedly, and tests to determine optimum receiver gain, scope intensity, photographic techniques, etc., could not be made before the firings began. Laboratory studies indicate that great improvements may result with the new photographic-recording indicator and the use of different photographic techniques. It appears desirable, therefore, that further tests be made before deciding on the final method of photographic recording.

Photography of a "dark trace" presentation is being investigated. Preliminary tests indicate that the edges of the signal blips are more sharply defined with the dark trace than with the
bright trace which is normally used. Use of the dark trace method also has the advantage of providing a negative for analysis, with the normal white-on-black presentation of the oscilloscope. Tests will be continued to determine whether the bright trace or dark trace method is more desirable for use in photographic recording.

4. Firing Error Computer

An electro-mechanical computer is being designed for rapid computation of the range and deflection errors of fall of shot in surface firings. In a tentative design, which has been drawn up on paper, the range and deflection errors of individual fall-of-shot positions would be obtained from radar data on the target and splash locations and from the line-of-fire angle. The radar ranges and bearings of the target and splash would be cranked into the computer from information received from the film recordings. The line-of-fire angle could be obtained as the difference in the true bearings of the target as seen from the towing and firing ships; or, an auxiliary computer might be used to determine the line-of-fire angle from data obtained with the firing error radar and a fire-control radar on the towing ship.

Servo motors and amplifiers from the AN/TPQ-2 mortar-location computer can be used in the construction of the proposed
Additional components needed, such as sine and cosine potentiometers, gears, and dials would be purchased.

A computer of the foregoing type could also be utilized in determination of the range and deflection errors of the mean point of impact of a salvo from the oscilloscope presentation.

C. Task C—Reflecting Properties of Small Surface Targets.

Little progress was made in small target measurements during the month of June, owing to changes in personnel assigned to the field research unit at the Navy Mine Countermeasures Station, Panama City, Florida. Training of new members of the field research unit, testing of instruments, modification of measuring equipment, and changes in operating procedure consumed the greater part of the month.

Measurements of the reflecting properties of small surface targets with the K-band AN/TPQ-2 were resumed in July. Tests at the 1000-yard range were completed, and the target stand and associated equipment were then moved to a new location at a range of 2300 yards. The old and new target locations are shown in Figure 5. Measurements during July were hampered by frequent rainfall. However, runs were made on the 12" diameter sphere and the 16" diameter cylinder at the range of 2300 yards.
Figure 5. Vicinity of U. S. Navy Mine Countermeasures Station, Panama City, Florida, showing target locations for radar observations in St. Andrew's Bay. (Distances from test site to target locations, o, are in yards.)
Data obtained during one run on the 16" cylinder indicated that
the echo signal strength is extremely sensitive to the angle of tilt
of the cylinder. During this run, the cylinder, which projected ap-
approximately four feet above the water surface, was tilted through
small angles toward and away from the radar. Variations in echo
strength as great as 20 db were obtained in repeating observations
at a given setting of tilt angle. The estimated accuracy of setting
the tilt angle was about 0.5 degree, and readings were taken at
settings of 0°, ±0.5°, ±1.0°, ±2.0°, etc. Theoretical calculations
of the free space reflection pattern indicate that large fluctuations
in signal strength are to be expected as the angle of tilt is varied.
These fluctuations are of an oscillatory nature and they decrease in
amplitude as the angle of tilt increases. Further measurements, us-
ing more refined methods, will be taken to provide additional data
concerning this phenomenon.

At present, the small target measurements are being made with
the K-band AN/TPQ-2 only, because of operational difficulties en-
countered in the use of the X-band system. Assignment of addition-
al personnel to the field research unit would be required in order
to make simultaneous measurements at both frequencies. Also, the
wider beam and longer pulse of the X-band radar make accurate measure-
ments more difficult than with the high resolution AN/TPQ-2. For
these reasons, it was decided to concentrate effort on the K-band studies with a view toward completion of the Task C measurements in September, 1948.

Arrangements are being made to measure return-signal strengths from small towed targets in St. Andrew's Bay, upon completion of the studies on fixed targets at the 2300-yard range. The Navy Mine Countermeasures Station will provide the necessary small craft and gear to perform these experiments. It will thus be possible to obtain return-signal strength data as a function of range and to determine maximum range performance of the AN/TPQ-2 on small surface targets. Periodic measurements will also be made of the echo strengths of buoys and other targets which are located in St. Andrew's Bay, at various ranges from the AN/TPQ-2 radar.

D. Task D—Small Surface-Target Tracking.

It is planned to make the measurements of echo strengths from small towed targets as they move toward and away from the radar in St. Andrew's Bay. Observations on moving targets will be made with the aid of photographic recordings of the A-scope presentation. The design and construction of auxiliary equipment to facilitate target tracking has been started. Laboratory tests indicate that high-speed photographic recordings of the signal strengths can be made by the
continuous film-motion technique employing the DuMont Oscillograph-Record Camera. Although the AN/TPQ-2 was not designed for tracking, the data so obtained should provide valuable information on the tracking potentialities of a high-discrimination K-band radar.

E. Personnel Additions.

The following personnel were added to the project staff during the months of June and July:

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Duties</th>
<th>Experience and Qualifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Babe M. Barnes</td>
<td>Technical Assistant (Machinist)</td>
<td>High School graduate, Bell Aircraft Precision Tool Shop experience.</td>
</tr>
<tr>
<td>Joseph A. Brady</td>
<td>Technical Assistant (Machinist)</td>
<td>High School graduate, Machine tool repair with Bell Aircraft.</td>
</tr>
<tr>
<td>Walter J. Cleveland</td>
<td>Technical Assistant</td>
<td>Senior in EE., Ga. Tech. Experience in State Engineering Experiment Station Photographic Laboratory.</td>
</tr>
<tr>
<td>Sue T. Dixon</td>
<td>Technical Assistant (Preparation of reports, etc.)</td>
<td>Agnes Scott College (3 yrs.), major in English and Mathematics. One year experience at Ga. Tech. as secretary on electronic research project.</td>
</tr>
<tr>
<td>Clarence E. Haynes</td>
<td>Technical Assistant (Machinist)</td>
<td>College work in engineering drawing and mathematics. Machine and die work with Bell Aircraft and others.</td>
</tr>
<tr>
<td>Name</td>
<td>Title and Duties</td>
<td>Experience and Qualifications</td>
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</tr>
<tr>
<td>William M. Holmes</td>
<td>Research Assistant (Member of Field</td>
<td>B.S. in Engineering Physics, Alabama Polytechnic Institute.</td>
</tr>
<tr>
<td></td>
<td>Research Unit)</td>
<td>Instructor in Mathematics at Ga. Tech. Experience as</td>
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<td></td>
<td></td>
<td>radio repairman.</td>
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<tr>
<td></td>
<td>development)</td>
<td>Experience in microwave propagation research.</td>
</tr>
<tr>
<td>Paula B. McKoin</td>
<td>Technical Assistant</td>
<td>University of Georgia (1 yr.). Business College. Secretarial</td>
</tr>
<tr>
<td></td>
<td>(Part-time assistant in preparation</td>
<td>experience.</td>
</tr>
<tr>
<td></td>
<td>of reports.)</td>
<td></td>
</tr>
<tr>
<td>Harry Michel</td>
<td>Technical Assistant (Machinist)</td>
<td>Two years' machine shop practice, Drexel Institute. Experience</td>
</tr>
<tr>
<td></td>
<td></td>
<td>with Bell Aircraft Machine Shops and others.</td>
</tr>
<tr>
<td>Evelyn Puckett</td>
<td>Research Assistant (Data Analyst)</td>
<td>A.B., Agnes Scott College, major in Mathematics and Physics.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experience in analysis with American Telephone Co.</td>
</tr>
<tr>
<td>Glen P. Robinson</td>
<td>Research Assistant (Computer Design)</td>
<td>B.S. in Physics, Ga. Tech. Three years' experience in Signal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corps, U. S. Army. Radio teletype experience, 1st</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lieutenant, Army Reserve.</td>
</tr>
<tr>
<td>Name</td>
<td>Title and Duties</td>
<td>Experience and Qualifications</td>
</tr>
<tr>
<td>---------------------</td>
<td>--------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>William B. Wrigley</td>
<td>Research Engineer (Receiver circuit design)</td>
<td>B.S. in Engineering Physics at Lehigh. Postgraduate work at Ga. Tech. Two years' at RCA electronic development labs. Five years' experience in U.S. Army (Captain) on maintenance of electromechanical computers, etc. One year with private enterprise on radar research. Major, Army Reserve.</td>
</tr>
</tbody>
</table>
IV. OUTLINE OF WORK FOR AUGUST.

1. Continuation of scanner design and development.
2. Beam pattern tests of elliptical-cone reflector.
4. Continuation of photographic recording tests.
5. Construction of control indicator console.
6. Continuation of AGC circuit development.
7. Completion of construction of photographic-recording indicator.
8. Preparation of technical report on splash characteristics and radar indications from splashes.
9. Continuation of measurements of the reflecting properties of small objects.

J. E. Boyd,  
Project Director

Approved:

Gerald A. Rosselot,  
Director
Georgia Institute of Technology
THE STATE ENGINEERING EXPERIMENT STATION
Atlanta, Georgia

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PROGRESS REPORT NO. 13
PROJECT NO. 124-27
CONTRACT NO. NORD 10020

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and
W. J. MILLER

AUGUST 31, 1948
SUMMARY

PART A - FRONT-ENTRY ANALYSIS MODEL

PART B - REFINEMENT PROJECTION OF FRONT ENTRANCE TUNNEL

PART D - SMALL SURFACE TARGET TRACKING EQUIPMENT

by

J. B. Boyd

and

W. J. Miller

AUGUST 31, 1969
PROGRESS REPORT NO. 13
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AUGUST 31, 1948
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IV. OUTLINE OF WORK FOR SEPTEMBER .................. 29
During the month of August, 1948, the State Engineering Experiment Station, Georgia Institute of Technology, continued the work on Contract NORD 10020, with major emphasis on Task B but with continued progress on Task C. Task A has been completed, as stated in the final report on that task.

Design studies and laboratory work under Task B have proceeded at a very satisfactory rate, and considerable construction work has been accomplished. A successful prototype reflector-and-feed assembly was completed and tested in the field. The beam pattern was found to lie within the designed widths in both the horizontal and vertical planes. Final design of the three-reflector antenna was begun as the month ended. The construction of the console, the design of which was mentioned in Progress Report No. 12, has progressed to the point where the control and indicator component units are being mounted in position. Cabling for interunit connection will begin in September, and the remainder of the components will be installed in the console.

Work under Task C continued at the Navy Mine Countermeasures Station at Panama City, Florida. Reflection measurements were taken on a metal cylinder 16 inches in diameter and 48 inches in length, at various angles of tilt and at a range of 2300 yards. Recordings of re-
Reflection measurements by means of a continuous film-motion camera were made. The new recording method appears to offer considerable promise of success in making significant measurements. The measurements of reflection from small objects will be continued, and the time previously planned for devotion to this work will be extended to permit the new technique to be studied more thoroughly.
II. INTRODUCTION

The general objectives of the work in progress under Contract
NOrd 10020 are as follows: (Task A, a theoretical and experimental
study of the requirements for rapid and accurate analysis of firing
errors, was completed in June, 1948, and a final report on that phase
of the project has been submitted.)

Task B: Modifications of Existing Equipment and/or
   Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of
   the Order of Magnitude of 5000 sq. cm. of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments
   Including Possible Minor Modifications of Such
   Equipment to Determine Their Potentialities for
   Effective Tracking of Small Surface Targets.
III. PROGRESS

A. Task B - Firing Error Analysis Radar.

Excellent progress has been made in the development of an experimental firing error analysis radar during the month of August, 1948. The pattern for this work was outlined in Technical Report No. 4, Radar Analysis of Surface Firing Errors, and in previous progress reports. There has been no change in this pattern, but the design studies have crystallized and construction work is proceeding rapidly.


The progress in the overall system design and integration work can best be visualized by reference to a system functional block diagram which has been brought up to date as of August 15, 1948. This diagram is presented as Figure 1. The significant differences between Figure 1 and the similar diagrams submitted in Technical Report No. 4 and Progress Report No. 11 are:

(a) the control and indicator units, previously shown as separate units, have been combined and are shown as the console group in the center of Figure 1;
(b) the modulator, the RF unit, and the scanner have been combined to form the antenna group;
(c) the photography group includes more detail than
Figure 1. Firing Error Radar System, Functional Block Diagram.
was previously shown; and
(d) the interconnection cabling has been indicated
more clearly, showing wave forms at strategic points.

2. The Console Group.

The frame of the console has been constructed, and the de-
sign of practically all of the components in the console group
has been completed. The assembly of the component units is well
under way, and the mounting of the units in the console has been
initiated. Cabling between units has been laid out in considerable
detail, and the installation of cables is beginning. It is ex-
pected that this entire group will be assembled and ready for
testing at the end of September. An artist's concept of the con-
trol and indicator console is shown as Figure 2.

As stated in Progress Report No. 12, particular attention is
being paid to the matter of location of parts and subunits with
a view to convenience in operation, maintenance, adjustment, and
repair.

The following controls will be located in the panels of the
control-indicator console which is illustrated in Figure 2:

(a) Range Panel (lower left panel) —

1) Range-marker positioning control

2) Range dial adjustment
Figure 2. Control-Indicator Console, Firing Error Analysis Radar.
3) Switch, continuous train, single marker

(b) Azimuth Panel (lower right panel) —
1) Azimuth scan-sector positioning crank
2) Azimuth dial adjustment
3) Azimuth-marker positioning crank
4) Azimuth-marker dial adjustment
5) Camera controls
6) Dial-light intensity adjustment

(d) Receiver Control Panel (upper center panel) —
1) Gain adjustment
2) Tuning adjustment
3) Automatic-frequency-control on-off switch
4) Automatic-gain-control sensitivity adjustment
5) Automatic-gain-control on-off switch
6) Azimuth target-blanking adjustment
7) Range target-blanking adjustment
8) Target-blanking on-off switch
9) Scope-blanking AGC adjustment, on-off switch

(d) Indicator Circuit Panel (upper right panel) —
1) Range-sweep delay adjustment
2) Vertical-gain adjustment
3) Horizontal-gain adjustment
4) Repetition-rate selector

(e) Scope Panel (lower center panel) —

1) Focus adjustment
2) Intensity adjustment
3) Horizontal-positioning control
4) Vertical-positioning control
5) Range-marker intensity adjustment
6) Azimuth-marker intensity adjustment

(f) System Control Panel (upper left panel) —

1) Power on-off switch
2) Power-enabling switch
3) Transmitter start switch
4) Transmitter run switch
5) Transmitter off switch
6) Scan-motor on-off switch
7) Pilot-light dimmer
8) Meters and fuse access.

Further information on the control-indicator console can be obtained from a listing of the major components with their functional subunits, as given below:

(a) The indicator circuit unit —

1) Modified AN/TPQ-2 range-sweep amplifier chassis
2) Range-sweep and unblanking circuits
3) Azimuth-sweep and blanking circuits
4) Repetition-rate oscillator-and-divider chassis
5) Movable azimuth-marker circuits

(b) Video unit —
1) Cathode ray tube
2) Blanking circuits
3) Unblanking circuits
4) Video amplifier stages
5) Fairchild Type A Camera

(c) High voltage rectifier
(d) Regulated rectifier
(e) Range unit
(f) Camera keying and control circuit
(g) Automatic-gain-control unit
(h) Servo amplifiers
(i) Various control circuits.

3. The Photography Group.

As reported in Progress Report No. 12, a new photographic-recording indicator unit has been constructed, with the exception of the video amplifier stages, which await the design of new automatic-gain-control features. The video stages have now been de-
signed; the photography group will be finished and research work begun with it in the near future. The complete unit can best be described by reference to Figure 1 and to lists of the front-panel controls and the internal subunits which pertain to it:

(a) Controls —
1) Range-sweep amplitude adjustment
2) Intensity adjustment
3) Range-marker intensity adjustment
4) Video clipping-level adjustment
5) Azimuth-marker intensity adjustment
6) Beam positioning and focus controls

(b) Subunits —
1) Cathode ray tube, 5CP11
2) DuMont Oscillograph Record Camera, Type 314
3) Video amplifier
4) Range-sweep generator and amplifier
5) Automatic-gain-control circuits
6) High voltage rectifier.

4. The Antenna Group.

During the month of August, an experimental reflector-and-feed assembly was completed and tested. This culminated research work of previous months in the design of a rapid-scanning antenna.
Progress Report No. 13
Project No. 124-27

Field tests of the experimental assembly indicated that the performance characteristics are well within the design specifications established prior to its construction. A horizontal beam width of approximately 0.65 degree and a vertical beam width of approximately 4.0 degrees were measured between the half-power points of the pattern in one-way transmission. This antenna will serve as a prototype for the design of the three identical elements of the rapid scanner to be used in the firing error radar.

A photograph of the experimental assembly, showing the reflector and feed arrangement, is presented in Figure 3. A view of the feed which illustrates its size by reference to a scale in inches is shown in Figure 4. The test site, together with some of the equipment used in the pattern measurements, can be seen in Figure 5. A degree scale was marked on the circumference of the circular table bearing the antenna structure and the transmitting equipment. A vernier device permitted readings to be made to ±0.05 degree.

The dark object on the upper shelf of the wooden structure is a walkie-talkie for communication with the receiving station 500 feet away. Figure 6 shows the receiving equipment with which relative signal strengths were measured as the antenna was rotated through an arc centered on the line between the antenna and the signal reception point.
Figure 3. Experimental Reflector and Feed, Firing Error Radar Antenna.
Figure 4. Antenna Feed, Experimental Firing Error Radar.
Figure 5. Test Site and Transmitting Equipment Used in Antenna Pattern Measurements.
Figure 6. Receiving Equipment, Antenna Pattern Measurements.
The tests were conducted on an athletic field and had to be completed hurriedly in order to avoid interference with other activities. However, beam patterns were repeated with no discernible error and are considered reliable enough to justify proceeding with the construction of the three-element antenna. Plans are in progress to set up an antenna pattern-measurement range in a location near the Georgia Tech campus which can be used on a continuous basis without interference from other activities.

As in the case of the preceding system components, some information concerning the nature of the antenna group can be had by reference to Figure 1 and by itemizing the major components of the group:

(a) Antenna —

1) Reflectors
2) Pillbox feeds
3) Microwave switch
4) Azimuth-marker generating discs
5) Azimuth-marker pickup coils
6) Mechanical driving mechanism
7) Scan-arc positioning servo mechanism

(b) RF unit —

1) Magnetron
2) TR and ATR units
3) RF connections to microwave switch
4) Modulator unit
5) Mixer and RF stages of the receiver system
6) Power supplies and controls.

The microwave switch listed above deserves some additional comment. Experimental design studies have been in progress on this item during the entire summer and have culminated in the production of a successful prototype. The switch is of the rotating type, with three outlets. Various refinements on the laboratory model have resulted in the excellent performance characteristic of constant and low standing wave ratio (1.15) over a 1% frequency band. Construction of the model to be used in the firing error analysis radar is now in progress.

After completion of the antenna field tests discussed earlier, attention was focused upon the ultimate design and construction of the firing error analysis radar rapid-scanning antenna. Final drawings of the antenna will begin to take form early in September, and mechanical construction will be started during that month. Completion of the antenna by December 15, 1948, is anticipated.

5. The AGC System.

The automatic-gain-control system, which has been commented
upon in Technical Report No. 4 and in previous progress reports, does not lend itself to classification under any one of the three major equipment groups of Figure 1, since its parts and its functions are distributed among the three. However, work on the AGC is of such importance as to justify special mention of it here.

The design of the system is substantially complete, and a functional block diagram of it is presented as Figure 7. The manner in which the AGC is designed to function is as follows: 1) the strengths of signals received on alternate scans of the rotating antenna system are sampled; 2) system gain levels during intervening scans are established at values determined, on some prearranged basis, by the amplitude of the sampled signals. The automatic control action will be applied to the video stages in the antenna, console, and photography groups. Assembly of the units of this system should be completed during the month of September, and those parts which will be contained in the console and photography groups will be installed in their final locations.

It now appears that the FEAR (firing error analysis radar) will be completely assembled and ready for preliminary performance tests in January, 1949. It is suggested that the Bureau of Ordnance consider tentatively that the FEAR will be ready for tests on actual splashes by February 1, 1949, and begin preliminary arrangements for the availabil-
Figure 7. Automatic Gain Control Circuit for Firing Error Analysis Radar.
ity of a ship to provide the splashes for observation.

B. Task C - Reflecting Properties of Small Surface Targets.

Experimental studies of the overwater reflecting properties of small objects were continued at the Navy Mine Countermeasures Station during the month of August. A considerable amount of significant data was collected in a series of runs on spheres and cylinders at the 2300-yard range. A more detailed investigation was made of the reflection pattern of a cylinder for small angles of tilt about the vertical, and the results indicated that under some conditions there is a marked similarity between the theoretical free space echo pattern and the experimental pattern for a cylinder projecting from the water. In order to facilitate further studies of this type of phenomenon, a new method of recording signal-strength data was devised. Preliminary tests with the new technique were so promising that plans for work under Task C were revised extensively. Members of the field research unit will return to Atlanta early in September, and the AN/TPQ-2 radar will be left in custody of a caretaker, pending design, construction, and calibration of target-control and photographic-recording equipment to be used in accurate quantitative measurements.

1. Photographic Recording of Target Reflection Patterns.

The photographic method of recording target signal-strength data employs the continuously moving film technique with an A-scope
presentation. The film moves parallel to the sweep line and records the target signal height for each pulse returned from the target. For uniform motion of the film the photographic record provides a rectangular plot of signal strength versus time. This photographic method is well suited to studies of echo strength as a function of target aspect or angle of orientation relative to the radar beam. For example, a rectangular plot of signal return versus angle of tilt for a cylindrical target may be obtained by rotating the cylinder at a constant angular rate about a horizontal axis.

Preliminary field tests of the photographic method of recording signal-strength data were made at the Navy Mine Countermeasures Station on August 11, 1948. A cylinder, 16 inches in diameter and 48 inches in length, was used as the target, at the 2300-yard range. The cylinder was mounted on the target stand so that it could be tilted in the vertical plane containing the radar line of sight. Typical photographic records obtained as the cylinder was tilted through a small angle, centered on its vertical position, are shown in Figures 8 and 9. Diagrams illustrating the direction of rotation and the location of the cylinder relative to the observing radar are included on the figures. Figure 8 shows the variation in the A-scope signal height for a run with the receiver gain adjusted so that the
Figure 8. Echo Pattern from Tilting Cylinder for Low Receiver Gain and for Angle of Rotation $\theta$ of Approximately 5 Degrees.
Figure 9. Echo Pattern from Tilting Cylinder for High Receiver Gain and for Angle of Rotation $\theta$ of Approximately 10 Degrees.
maximum signal was just below saturation; the results shown in
Figure 9 were obtained when the receiver gain was increased con-
siderably, so that the receiver was saturated on the main lobe of
the echo pattern. Because of limitations in the existing equipment,
no attempt was made to record the instantaneous angular position of
the cylinder or the absolute magnitude of signal strength. How-
ever, it is estimated that the spacing between successive minima in
the echo pattern is about 0.5 degree and that the scale of signal
amplitude is approximately linear below the saturation level.

Recent runs using old techniques of measurement have verified
the oscillatory nature of the echo pattern from a tilting cylinder.
The amassing of sufficient data to disclose the fine structure of
the echo pattern by means of the old technique, however, is a to-
dious and time-consuming process. Photographic recording provides
a rapid method of collecting data which reduces many of the opera-
tional variables inherent in the slow, step-by-step procedure of
visually measuring the target echo strength versus tilt angle by
comparison with a signal generator pulse. A complete run using
the photographic method of recording requires only a few seconds
and provides thousands of points on the echo-pattern curve. Fur-
thermore, the effects of receiver drift, signal-generator drift,
tide variations, sea-clutter variations, etc. are minimized.
At the present time work is progressing on the design and construction of suitable target-control equipment and improved photographic-recording equipment which will permit accurate quantitative measurements of target reflection patterns.

2. **Echo Strength as a Function of Target Height.**

As a result of interference between direct and water-reflected rays, a cylinder projecting from the surface of the water is not uniformly illuminated. The interference pattern at a given range, or the variation of signal strength with height above the surface, may be determined by measuring the echo from a sphere as a function of the distance of the sphere above the water. Recent runs using a 12"-diameter sphere at the 2300-yard range have revealed a lobe structure considerably different from the theoretical pattern for a standard atmosphere. The spacing between maxima and minima is reduced, apparently because of the greater water vapor density and, consequently, greater index of refraction close to the surface of the water. For example, during three successive runs on August 26, maxima were found at heights of 2.5 feet and 7.5 feet above the surface, as compared to the predicted 3.3 feet and 10.0 feet, respectively, for a standard atmosphere. Calculations of phase differences, based on meteorological data obtained during the runs, indicate that the interference lobe structure should have been compressed...
approximately as observed. It is planned to continue the measurements on spheres and the associated meteorological observations, along with the studies of echo patterns from tilting cylinders, in order to provide supplementary data needed in the interpretation of the experimental results.

C. Task D - Small Surface Target Tracking.

In view of the new developments in connection with the photographic recording of signal strengths, it was decided to postpone tracking tests on moving surface targets. Photographic methods should prove of great value also in the continuous recording of data on tracking runs.

Since the existing AN/TPQ-2 is not suitable for target tracking, it may prove desirable to postpone tracking tests further until the experimental firing error radar, now being constructed under Task B, has been completed. Manual tracking controls are being provided for the firing error radar, and it would not be economical to carry out a separate modification of the AN/TPQ-2 at Panama City in order to permit limited tracking tests.

D. Personnel Changes.

1. Personnel Additions.

Two new employees were added to the project staff during the month of August:
Name
Roy C. LeCraw, Jr.

Constance D. Seacord

Title and Duties
Research Assistant (Part-time laboratory assistant)

Experience and Qualifications
Senior in Physics. Attended Army radar and radio schools and served as radar technician for three years.

A.B. - Georgia State College for Women, major in mathematics. Two years' experience in Pilotless Aircraft Research Division of NACA, Langley Field, Va., in data reduction and mathematical analysis.

2. Personnel Losses.

T. E. Roberts, Research Engineer, Research Assistant Professor, was granted leave of absence by the school in order that he might continue his graduate studies in applied physics at Harvard University.
IV. OUTLINE OF WORK FOR SEPTEMBER

1. Completion of construction of a laboratory model of the control-indicator console for the experimental firing error radar.

2. Completion of video amplifier development, and laboratory testing of photographic-recording indicator.

3. Continuation of AGC circuit development.

4. Continuation of design and construction of reflector-feed assembly for FEAR.

5. Mechanical design of rotating assembly for antenna system.

6. Construction of three-way RF switch for FEAR.

7. Development of additional laboratory equipment for antenna feed pattern and phase measurements.


11. Design and construction of photographic-recording oscilloscope for high writing speeds.

J. E. Boyd,
Project Director

Approved:

W. J. Müller
Project Administrator

Gerald A. Rosselot,
Director

Page 29 of 29 pages
PROGRESS REPORT NO. 14

PROJECT NO. 12h-27

CONTRACT NO. NORD 10020

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD

and

W. J. MILLER

SEPTEMBER 30, 1948

UNCLASSIFIED
PROGRESS REPORT NO. 14
PROJECT NO. 124-27
CONTRACT NO. NORD 10020

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and

W. J. MILLER

SEPTEMBER 30, 1948
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I. SUMMARY

During September, 1948, the State Engineering Experiment Station, Georgia Institute of Technology, continued work on Tasks B, C, and D of BuOrd Contract NOrd 10020 as outlined in Progress Report No. 13; major emphasis was placed on Task B, the development of a firing error analysis radar (FEAR).

The frame for the rapid-scanning antenna was completed, and construction work on the FEAR Control-Indicator Console progressed to final stages. Preliminary arrangements were made for mobilizing the FEAR by mounting it on a truck chassis furnished by Georgia Tech. Automatic Gain Control design studies reached the point where tests of prototype circuits are needed. These tests await delivery of equipment which has been ordered.

Task C and Task D work at the Navy Line Countermeasures Station, Panama City, Florida, was discontinued and the AN/TPQ-2 radar equipment placed in maintenance status, pending construction of new target-control equipment and a camera recording oscilloscope at Georgia Tech. These equipments will be implemental in data gathering by the continuous film-motion scope-photography technique.
II. INTRODUCTION

The general objectives of the work in progress under Contract NOrd 10020 are as follows: (Task A, a theoretical and experimental study of the requirements for rapid and accurate analysis of firing errors, was completed in June, 1948, and a final report on that phase of the project has been submitted.)

Task B: Modifications of Existing Equipment and/or Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of the Order of Magnitude of 5000 sq. cm. of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments Including Possible Minor Modifications of Such Equipment to Determine Their Potentialities for Effective Tracking of Small Surface Targets.
A. Task D—Firing Error Analysis Radar (FEAR).


There has been no significant change in the concept of the overall radar system which was presented as Figure 1 in Progress Report No. 13, August 31, 1948. All major design studies for the experimental FEAR are complete, and rapid progress is being made in the physical construction and assembly of units. Preparation of detailed schematic diagrams of the various functional units is being pushed forward concurrently with their development.

2. Control Indicator Console.

Continued progress has been made during September on the construction of the FEAR Control-Indicator Console. Views of this unit, with sides and rear panels removed, are shown in Figures 1, 2, 3, 4, and 5. Figures 1, 2, and 5 include the DuMont 248 Test Oscillograph, with power supply, on its roll-around table mounting. The Fairchild Type A Oscillograph Record Camera may be seen in the views which show the front of the Console. An itemized listing of important components of the Console Unit was given in Progress Report No. 13. The locations of the major components are shown in Figure 3. In designing the Control-Indicator Console, provisions were made for it to serve as a trouble-shooting center for the entire radar system.
Figure 1. FEAR Control-Indicator Console, Showing Operator's Position and Test Oscillograph.
Figure 2. Rear control-indicator console and test oscilloscope, front view.
Figure 3. FEAR Control-Indicator Console, Top View, Range Unit Cover Removed, Indicator Circuit Unit Partially Withdrawn From Chassis.
Figure 4. FEAR Control-Indicator Console, View From Left Side, Showing Regulated Rectifier Power Supply at Rear.
Figure 5. FEAR Control-Indicator Console, Rear View. (Long cable at rear of indicator circuit unit allows removal of this unit from front panel to facilitate servicing.)
3. **Auxiliary Photographic Indicator**

During September, some finishing touches were added to the Auxiliary Indicator which has been designed and constructed by Georgia Tech engineers for use in conjunction with the DuMont Type 3114 Oscillograph Record Camera. Final adjustment of the AGC circuits in the video amplifier stages of the unit remains to be accomplished. This work will require the assembly of the complete radar system before it can be finished.

An itemized list of the major components of this indicator was included in Progress Report No. 13. Figure 6 shows a front view of the indicator with the DuMont Type 3114 Camera in position for continuous film-motion recording of splash patterns. Figures 7, 8, and 9 (right side, left side, and rear views, taken with rear and side cover-plates removed) illustrate the circuit-construction work which is typical of the Georgia Tech circuit development and construction now in progress. The recording camera appears in all of the views presented, and the electronic camera-control unit can be seen in Figure 6 and Figure 9. Figures 7 and 8 present a clear view of the periscope arrangement which permits viewing the scope while photography is in progress.

4. **The Rapid Scan Antenna**

The construction of the rotating assembly for the FEAR wide-angle rapid-scan antenna was initiated early in September, and considerable
Figure 6. FEAR Auxiliary Photographic Indicator with DuMont Type 314 Camera, Front View, Camera Control Unit at Right.
Figure 7. FEAR Auxiliary Indicator for Continuous Film-Motion Photographic Recording of Splash Patterns, Right Side View.
Figure 8. FEAR Auxiliary Indicator for Photographic Recording of Splash Patterns, Left Side View.
Figure 9. FEAR Auxiliary Indicator for Photographic Recording of Splash Patterns, Rear View.
progress was made on it during the month. The frame for mounting the three symmetrically arranged reflectors of the antenna system was completed. Two views of the frame in process of construction are shown in Figures 10 and 11. Sheet aluminum was used in the construction of the frame, and metal was removed in the form of lightening holes, which can be seen in the illustrations, in order to save weight. The total weight of the reflectors and the supporting frame should be approximately 100 lbs. when the structure is completed.

The microwave switch for use with the rapid-scan antenna has been approximately two-thirds completed. Detailed drawings of the mechanical components of this switch are nearing completion.

The three antenna "haw horn" feeds have been completed, plated, and tested. The prototype for these feed horns was described and illustrated in Progress Report No. 13.

Installation of the microwave switch at the center of rotation of the antenna-supporting column and mounting of the feed horns on the reflectors will begin in October.

It is anticipated that the antenna will undergo beam-pattern tests and adjustments sometime in November, 1948, and be ready for integration into the complete radar system in December, 1948.
Figure 10. FEAR Rapid-Scan Antenna Frame, During Construction.
Figure 11. FEAR Rapid-Scan Antenna Frame, Close-Up View.

Task C measurements at the Navy Mine Countermeasures Station, Panama City, Florida, were suspended early in September; the AN/TPQ-2 radar was placed in a temporary maintenance status, pending design and construction of new target-control equipment and a camera recording oscilloscope. Field measurements at the Navy Mine Countermeasures Station will be resumed upon completion of the new equipment, which will utilize the continuous film-motion technique in the rapid recording of target reflection patterns. Considerable progress has been made in the construction of both the target-control unit and the recording oscilloscope, and it is estimated that all of the new equipment will be completed early in November.

1. Target Control Unit.

The target control unit was designed to fulfill two requirements. The first objective was to produce rapid angular motion in the vertical and horizontal planes and, simultaneously, to provide a means of recording the instantaneous angular position of the target. The second objective was to build a remote control unit with which the target position could be accurately reset. The specifications for the target stand are:

- Azimuth rotation: 6 x 360°
- Azimuth indicator solsyn: 0-90° and repeat
- Azimuth marker: every 5°
- Azimuth rate of rotation: 90°/sec.
Elevation rotation
- 45° from vertical

Elevation indicator selsyn
- 0-10° and repeat

Elevation markers
- every 1°

Elevation rate
- 17°/sec.

The azimuth and elevation selsyn indicators permit the operator to set the target remotely. The azimuth and elevation markers will be transmitted by radio link to the recording camera and there recorded directly on the film strip. Since considerable difficulty has been experienced with backlash in previous target stands, every effort is being made to eliminate backlash in this target-control unit.

2. Camera Recording Oscilloscope

The recording technique to be employed in Task C studies necessitates the use of an A-scope type of presentation. Since the AN/TPQ-2 lacks this type of presentation and existing commercial oscilloscopes are not readily adaptable for the purpose, an oscilloscope was designed specially to meet the operational and photographic requirements involved in the problem. In designing the instrument, however, a considerable degree of flexibility has been aimed for, so that the unit could be used in laboratory work or with other recording techniques. The cathode ray tube employed is the type 5RP-11A, which permits photographic recording of high writing rates. Specifications on the electrical characteristics are:
3. Analysis of Task C Data.

A considerable amount of data on the overwater reflecting properties of spheres and cylinders was collected in the measurements at the Navy Mine Countermeasures Station during the spring and summer months. Although more refined methods of measurement of reflection patterns are being developed, it is believed that much of the data already obtained are of sufficient significance to justify a detailed analysis and the preparation of a preliminary report on the results.

In order to facilitate analysis, the data have been collected and reduced to a more usable form: all information pertaining to each experimental run has been compiled on a master sheet, incorporating meteorological readings and rough measurements on the state of the sea. Analysis of the data on reflections from spheres has been started.

It is believed that the analysis will yield significant information on propagation factors—such as, the coefficient of reflection of the sea surface, and the changes in interference lobe structure resulting from vertical gradients of the index of refrac-
tion of the atmosphere. It is expected that the effective radar
cross sections of small surface targets will depend to a considerable
extent on the propagation conditions.

C. Task D - Small Surface-Target Tracking.

Task D measurements at the Navy Mine Countermeasures Station have
been postponed as a result of the decision to develop new equipment for
the photographic recording of target reflection patterns. It is expected
that photographic recording techniques which are being developed primarily
for use in Task C measurements will also be of value in connection with
Task D. Experimental work under Task D awaits completion of the measure-
ments under Task C and the availability of radar equipment which is suit-
able for target tracking.

D. Personnel Changes.

The turnover of personnel on the project staff was abnormally large
during the month of September, when a number of temporary employees, who
had been hired for the summer period only, returned to their school duties.
In addition to these temporary employees, the project has recently lost
the services of several experienced members of the research staff, who
resigned in order to continue their graduate studies. However, the
vacancies are being filled gradually, and it is believed that the time
schedule given in the report on the conference held in BuOrd September
9, 1948, can be maintained.
1. Personnel Additions.

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<td>C. A. Wong</td>
<td>Technical Assistant (Mechanical draftsman)</td>
<td>B.S. in M.E. at Georgia Tech in 1947. Wartime study of aircraft engines and their maintenance at Yale University. Experience in machine shop work. Aircraft maintenance officer in Army for six months.</td>
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<tr>
<td>Anne Penn</td>
<td>Secretary (General secretarial duties, report preparation, etc.)</td>
<td>High school graduate. Clerk-typist at Camp Wheeler for two years. Receptionist in physician's office for 2-1/2 years.</td>
</tr>
<tr>
<td>Leta Smith</td>
<td>Secretary (General secretarial duties, report preparation, etc.)</td>
<td>Graduate of Roosevelt High School in Washington, D.C. Secretary in United Nations Relief and Rehabilitation Administration, Washington, D.C., for three years.</td>
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2. Personnel Losses.

- L. M. Baggett, Research Assistant
- Sue Dixon, Secretary
- W. M. Holmes, Technical Assistant
- E. T. Hungerford, Research Assistant Professor
- R. C. LeCraw, Research Assistant
- H. W. Long, Research Assistant
- Betty Malaiier, Secretary
- F. A. Stovall, Research Assistant
IV. OUTLINE OF WORK FOR OCTOBER

1) Continuation of antenna construction.

2) Completion of R.F. switch.

3) Mounting of feeds on rotating assembly and of R.F. switch in the shaft.

4) Construction of test equipment for simulating azimuth signals.

5) Completion of construction of console units and AGC circuits.

6) Continuation of receiver tests and photographic tests.

7) Completion of construction of target control unit.

8) Continuation of construction of camera recording oscilloscope.

9) Analysis of data obtained in Task C measurements.

Approved:

J. E. Boyd,
Project Director

W. J. Miller,
Project Administrator

Gerald A. Rossdot,
Director
PROGRESS REPORT NO. 15
PROJECT NO. 124-27
CONTRACT NO. NORD 10020

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and
W. J. MILLER

OCTOBER 31, 1948
PROGRESS REPORT NO. 15
PROJECT NO. 124-27
CONTRACT NO. MORD 10020

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and
W. J. MILLER

OCTOBER 31, 1948
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During October, 1948, the State Engineering Experiment Station, Georgia Institute of Technology, continued the development of a firing error analysis radar (FEAR) under Task B of Contract NOrd 10020. The Task B development work consisted of continuation of the construction of a rapid scanning antenna and the assembly and testing of a FEAR control-indicator console.

Work on Tasks C and D continued, but was limited to the analysis of previously gathered data on the reflecting properties of small objects and to the construction of improved target mounting, control, and data-recording facilities.

Preliminary arrangements were started to procure a test site on the Gulf Coast of Florida for use in evaluating and adjusting the FEAR in conjunction with a firing ship which has been scheduled by the Navy to assist in this work during the month of February, 1949. The Navy Mine Countermeasures Station, Panama City, Florida is assisting in the arrangements.
II. INTRODUCTION

The general objectives of the work in progress under Contract NOrd 10020 are as follows: (Task A, a theoretical and experimental study of the requirements for rapid and accurate analysis of firing errors, was completed in June, 1948, and a final report on that phase of the project has been submitted.)

Task B: Modifications of Existing Equipment and/or Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of the Order of Magnitude of 5000 sq. cm. of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments Including Possible Minor Modifications of Such Equipment to Determine Their Potentialities for Effective Tracking of Small Surface Targets.
III. PROGRESS

A. Task B—Firing Error Analysis Radar (FEAR).


There has been no change in the fundamental design of the FEAR system. The design was described in the Final Report of Task A, "Radar Analysis of Surface Firing Errors", and in previous progress reports. Construction, assembly, and integration of the various units into the system was continued during October, 1948. Numerous minor difficulties were encountered and overcome. One of the most significant of these was the replacement of a magnetic azimuth marker and trigger pulse-originating device with one which utilizes photoelectric cells in its operation. The new system generates marker pulses by means of a toothed disc which rotates at three times the antenna speed. The 15-degree bearing markers are generated by the disc modulating a beam of light falling upon a photoelectric cell. A second photoelectric cell, operating in conjunction with a light source and slots in the disc, generates an azimuth-sweep dead-time pulse which was formerly generated by a multivibrator initiated by magnetic sweep triggers. A modulator gating circuit will be incorporated in the system so that the magnetron will not be pulsed during the antenna switching interval, "dead time." Preliminary tests indicate that the new photoelectric system will be much superior to the magnetic one.
2. Control-Indicator Console.

The FEAR control-indicator console has been described and illustrated in Progress Reports Nos. 13 and 14. It is a complex assembly of electronic circuits which perform a variety of functions, and laboratory testing of the circuits has proved to be a tedious process involving many man-hours of careful work. This work is proceeding as rapidly as can be expected, and it is believed that the console will be ready for use by the time the antenna unit is completed. Several items in the console are being redesigned to improve performance.

The use of the photocell system in the generation of azimuth markers at the antenna has eliminated considerable pattern "jitter" on the B-scope indicator in the console. Redesigned frequency doubling circuits in the range unit have eliminated irregularities in the magnitude and spacing of the 500-yard range markers in both the B-scope and the photographic recording indicator. Positive identification of the range marker which corresponds to the reading on the range dial is made possible at all times by having this particular marker appear as a brighter trace than the other markers, spaced at 500-yard intervals on the scope pattern. The laboratory tests have also indicated the necessity for improving the linearity of the range sweep and the basic azimuth sweep. These improvements will be completed in the near future.
3. Photographic Recording Indicator.

Tests have been made of the photographic recording indicator, which was described in Progress Reports Nos. 12 and 13. The tests indicate that favorable results may be expected from the dark-trace photographic technique which is being employed. Some modifications in the photographic recording indicator have been made as a result of the tests. The video amplifier contained in the unit has been compensated in order to provide optimum transient response and it appears to be satisfactory, although its frequency response is not as good as the video amplifier contained in the control-indicator console. Further investigations of these video characteristics will be made.

4. The Rapid Scan Antenna.

Mechanical construction of the rapid scan antenna described in the Final Report of Task A continues at a satisfactory rate, although progress has not been quite as rapid as was anticipated. The microwave switch has been completed and was undergoing tests at the end of the month. The reflectors have been mounted in place on the frame described in Progress Report No. 14. A pedestal which will support the rotating antenna has been designed and is in process of construction. In general arrangement, it will resemble the artist's concept presented in the Final Report of Task A, but the details of construction are such that its appearance may differ considerably. The drive-motor
assembly has not yet been started but will be initiated in November.

The antenna design group has devoted considerable time to planning for field performance tests of the antenna. It is expected that these tests will begin in the latter part of November. Antenna beam pattern tests will be carried out on the campus, utilizing a tower for mounting receiving equipment which will permit field strength measurements. A 42-foot steel tower has been procured for this purpose. It will be erected early in November in a position about 1000 feet from the Experiment Station and in a direction such that there is a clear field of view from the radar antenna mounted near the Station, with no intervening objects which might create interference and pattern distortion. The antenna pedestal will be mounted on concrete pillars at the test site so that test results will not be adversely affected by movement of the supporting structure. It now appears that the antenna assembly and test work will be completed early in January, 1949.

5. FEAR Tests and Final Adjustments.

It is considered that the final capabilities of the FEAR can be determined only by tests which involve the actual observation of projectile splashes. Two project representatives visited the Navy Mine Countermeasures Station, Panama City, Florida with the objective of making arrangements for a test site which will permit splashes laid down by a firing ship to be observed from a position on the shore.
A description of a similar operation was presented in the Final Report of Task A. For the forthcoming tests, now tentatively scheduled for February, 1949, it is planned to arrange for a new site which will permit an operation of this sort with less difficulty and expense than was experienced during the Task A studies. A site about 20 miles northwest of the Navy Mine Countermeasures Station was visited and appeared to be suitable. It has the necessary qualifications of remoteness from populated areas, favorable sea bottom contour near the shore, and considerable improvement in accessibility as compared with the site previously used near Port St. Joe, Florida. Efforts are being made to obtain permission to use the location, but arrangements are not yet complete.


Considerable progress was made in the construction of new equipment to be utilized in the photographic recording of target reflection patterns, but lack of a few essential components has delayed completion of the two major units: the target control unit, and the camera recording oscilloscope. It is now expected that all the new equipment will be ready for movement to Panama City about December 1, 1948.

1. Target Control Unit.

Mechanical construction of the target control unit is essentially complete. Remaining to be constructed are the watertight covers and the remote control box. In addition, the wiring must be installed.
Barring unforeseen difficulties, it is expected that the target control unit will be completed about November 15, 1948.

Photographs of the partially completed target control units are shown in Figures 1, 2, and 3. At the time these photographs were made, the watertight covers and the electrical wiring had not been installed. Figures 1 and 2 present two views of the inclination mechanism which is mounted on the rotating azimuth plate. Figure 3 shows the azimuth mechanism in an inverted view of the stationary azimuth plate. When assembled the rotating azimuth plate rests on the stationary plate and is keyed to the azimuth shaft. The complete unit is then mounted on a large tripod which provides a method of leveling the unit. The various data and driving gear-trains are adjustable so that the effects of wear may be counteracted.

2. Camera Recording Oscillograph.

The design of a camera recording oscillograph with an A-type presentation was described in Progress Report No. 14. Progress on the oscillograph has been slow because of delays in the delivery of certain essential components. The power supply for the oscilloscope is now complete except for its cabinet. It is expected that the entire unit will be completed by the end of November.
Figure 1. Target Inclination Mechanism Mounted on Rotating Azimuth Plate of Target Control Unit.
Figure 2. Target Inclination Mechanism, Showing Data Take-off Gear Train.
Figure 3. Target Azimuth Mechanism Mounted on Stationary Azimuth Plate of Target Control Unit.
3. Analysis of Task C Data.

Further studies have been made of the data obtained during the spring and summer months by the old methods of measurement. Analysis of the standard target runs, in which echo strength was measured as a function of antenna elevation angle, has been completed. Analysis of the sphere-interference runs, in which echo strength was measured as a function of height of the sphere above the water surface, at ranges of approximately 1000 yards and 2500 yards, has commenced, but little progress has been made up to this time. Analysis of meteorological data obtained in connection with the standard target and sphere-interference runs is nearing completion. Plots of the modified index of refraction as a function of height (M-curves) have been prepared from the meteorological data. An attempt will be made to correlate the sphere-interference run results with the observed M-value distributions.

The data obtained in the standard target runs have yielded information on the vertical beam pattern of the AN/TPQ-2 radar and on the reflection coefficient of the sea surface at K-band for a grazing angle of approximately one degree. Although the results are not considered conclusive, because of possible errors in measurement, it is indicated that the reflection coefficient is about 0.8 at a grazing angle of one degree.
It appears doubtful that more definite information can be derived from further analysis of the existing standard target run data, but much has been learned from their study which should contribute to better planning and execution of future operations under Task C.

C. Task D—Small Surface Target Tracking.

Work directed specifically toward solution of Task D has been postponed, awaiting results of further tests under Task C and availability of equipment which is suitable for the radar tracking of small surface targets.

D. Personnel Changes.

Two additional members were added to the present staff during the month of October, 1948.

1. Personnel Additions.

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Duties</th>
<th>Experience and Qualifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. C. Hurst</td>
<td>Technical Assistant (Electrical draftsman)</td>
<td>High School; Business School; Radio Trade School; E.E. Junior at Ga. Tech.; three years Army experience and training, Radio Repair School, Ft. Monmouth, and Radio Operator and Mechanic School, Scott Field.</td>
</tr>
</tbody>
</table>
Title and Duties

H. W. Mauldin, Jr.  Research Assistant

Experience and Qualifications

B.S. in E.E.; General Electric Co., Electronics Dept.; and M.I.T. Radiation Lab.; four years' experience includes work on airborne radar and wave-guide development in 10 cm., 3 cm., and 1 cm. bands.
IV. OUTLINE OF WORK FOR NOVEMBER

1) Assembly of rapid scan antenna and pedestal.
2) Preparation for and commencement of antenna pattern measurements.
3) Commencement of antenna drive mechanism construction.
4) Continuation of tests and improvements on control-indicator console.
5) Tests of receiver and AGC system.
6) Construction of system junction box.
7) Continuation of tests and improvements on photographic recording indicator.
8) Assembly of disc and photo-cell trigger device on antenna unit.
9) Completion of oscillograph for photographic recording of small surface target echo patterns.
10) Completion of control unit for small surface targets.
11) Continuation of analysis of existing Task C data.
12) Assembly and development of necessary auxiliary photographic equipment for splash recording.

Approved:

J. E. Boyd,
Project Director

W. J. Mullan,
Project Administrator

Gerald A. Rosselot,
Director
Georgia Institute of Technology
THE STATE ENGINEERING EXPERIMENT STATION
Atlanta, Georgia

PROGRESS REPORT NO. 16
PROJECT NO. 124-27
CONTRACT NO. NORD 10020

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and
W. J. MILLER

NOVEMBER 30, 1948

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      AND
      TASK D - Small Surface Target Tracking Equipment
      By
      J. E. BOYD
      and
      W. J. MILLER
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I. SUMMARY

During November, 1948, the State Engineering Experiment Station, Georgia Institute of Technology, continued the development of a Firing Error Analysis Radar (FEAR) under Task B of Contract NOrd 10020. Construction of the pedestal for the FEAR Rapid Scan Antenna System was completed, and the driving mechanism was tested. Concurrently, laboratory tests of the FEAR Control-Indicator Console and the Photographic Indicator Unit were carried out. A motor van was prepared for installation of the radar units, and considerable cabling between units was completed. A tower and a solid mount for the radar antenna were erected near the experiment station for use in field performance tests of the antenna. These tests will begin early in December, 1948.

The construction of target mounting, control, and data-recording facilities for use in the measurement of reflections from small surface targets under Task C of the contract was continued, and the work was nearing completion at the end of November. Analysis work under Task C was continued during the month. Gathering of data under Tasks C and D will be resumed in December, 1948.

It appears that the FEAR equipment will be ready for use in the evaluation studies on the Gulf Coast of Florida, in February, 1949, as tentatively scheduled.
II. INTRODUCTION

The general objectives of the work in progress under Contract NOrd 10020 are as follows: (Task A, a theoretical and experimental study of the requirements for rapid and accurate analysis of firing errors, was completed in June, 1948, and a final report on that phase of the project has been submitted.)

Task B: Modifications of Existing Equipment and/or Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of the Order of Magnitude of 5000 sq cm of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments Including Possible Minor Modifications of Such Equipment to Determine Their Potentialities for Effective Tracking of Small Surface Targets.
III. PROGRESS

A. Task B - Firing Error Analysis Radar (FEAR).


Construction of all the major units of the FEAR system has been completed. Work during the month of November consisted mainly of an integration, testing, and refinement process. As is usually the case, various subunits of the electronic equipment, which appeared to be satisfactory on the drawing board and in the individual unit bread-board stages, demonstrated need for minor refinements and improvements when they were operated as integral parts of the system. It is anticipated that the refinement and improvement process will continue for some time. Final electrical testing of the complete radar must await installation of the system in the mobile van and should begin about December 20, 1948, after antenna pattern tests have been conducted.

2. Control-Indicator Console.

The construction, wiring, and integration of the various components of the FEAR Control-Indicator Console have been completed. Tests with laboratory simulated signals have indicated that its performance will be satisfactory. During the first tests, it was found that the linearity of the range sweep needed improvement, and this has been accomplished. The sweep can be adjusted so that it
is linear within one per cent of the range coverage interval. Non-linearity troubles have been eliminated from the console azimuth sweep also, and the azimuth scale is linear within one per cent throughout its 90-degree coverage. During December, the finishing touches will be applied: cabinet side panels will be installed, switches and controls will be properly labeled, shock mountings will be constructed, and the console will be mounted in the van with the remainder of the system. It is expected that some of the preliminary electrical tests of the complete system will be accomplished during the latter part of December 1948.

3. Photographic Recording Indicator.

Construction of the Photographic Recording Indicator, designed for use in conjunction with the DuMont Type 314 Oscillograph-Record Camera, has been completed. Delivery of a new camera with a fast lens (f1.5) is expected in December. Some additional tests will be performed in the laboratory when the new camera arrives. The Photographic Recording Indicator will be mounted in the van, near the Control-Indicator Console, when the complete system is assembled.

4. Junction Box.

A Junction Box, which will be mounted in the antenna pedestal, has been completed. This box will serve as a power control assembly at the antenna and as a convenient connecting point for power cables, synchro cables, etc. It will house part of the AGC System and the
modulator trigger gate circuit. System Power Controls, located on the
Control-Indicator Console, will be duplicated on the front panel of
the Junction Box.

5. Rapid Scan Antenna.

A long and difficult period of precision antenna design and con-
struction was brought to a successful end during the month of Novem-
ber. After the three-way rapid scan antenna was mounted on its pedes-
tal and the driving mechanism installed, it was rotated at the de-
signed speed of 200 rpm with virtually no vibration. Three views of
this antenna as it was first rotated, without the feed horns and their
supporting arms, are shown in Figures 1, 2, and 3.

Some difficulty was experienced with the microwave switch which
mounts within the central supporting column. The switch was dropped
and damaged while in the hands of a commercial concern for silver
plating, and some of the parts had to be replaced, involving some de-
lay in the final assembly of the complete antenna. At the end of
November, repairs on the switch were completed and the replacement
parts were again in the hands of the plater. It is anticipated that
the feeds will be installed and that the antenna field pattern tests
will begin early in December. It is further expected that the antenna
will be mounted in the van and ready for preliminary system electrical
tests before the end of December.
Figure 1. FEAR Rapid Scan Antenna, Top View, Showing Method of Support of Top Bearing. Feed Horn Supports Are on Box at Right.
Figure 2. FEAR Rapid Scan Antenna, Less Feeds, Feed Supports, and Microwave Switch. Front View of Pedestal.
Figure 3. FEAR Rapid Scan Antenna, Side View of Pedestal, Showing Rear Column Bracing and Location of Driving Motor and Speed Reduction Belt Drive.
6. Antenna Pattern Test Site.

Considerable effort was devoted to the development of a test site suitable for making antenna pattern measurements at K-band. Project engineers erected a 48-foot tower at a location directly across an open area, called Drill Field, from the State Engineering Experiment Station. An unobstructed transmission path 750 feet in length was thus made available for narrow beam radar pattern tests. Receiving and field strength measuring equipment will be mounted on an eight-foot square platform approximately six feet below the top of the tower. The actual receiving antenna will be clamped on a small support rising about two feet above the top of the tower proper, approximately 50 feet above ground level. The antenna under test will be mounted on a concrete pedestal which has been erected near the station. A view of the tower from the antenna location is shown in Figure 4. A closer view of the tower, taken while it was being erected, is presented in Figure 5. The wires which can be seen in Figure 4 will not interfere with the pattern measurements since they lie well above the path of the beam. Arrangements have been made with Georgia Tech administrative officials to prohibit parking in the area directly in front of the antenna site while measurements are in progress. Pattern tests of the rapid scan antenna will begin at this location early in December 1948, and should be completed in about one week of good weather. It is anticipated that the antenna beam width
Figure 4. Antenna Pattern Measurement Test Site, Showing Receiving Tower in Background, Center. View Taken From Antenna Location.
Figure 5. Antenna Pattern Measurement Receiving Tower, in Process of Construction. Wooden Pole for Power Line is Seen at Right of Tower.
will be less than 0.7 degree, a value well within that specified in the Task A Final Report, "Radar Analysis of Firing Errors," June 30, 1948.

B. Task C - Reflecting Properties of Small Surface Targets.

Construction of new equipment which will utilize the continuous film-motion technique in rapid recordings of target echo patterns was nearing completion at the end of the month. It is expected that construction and laboratory tests of the equipment will be completed during the first week in December. Measurements of the over-water reflecting properties of small surface targets will then be resumed at the Navy Mine Countermeasures Station, Panama City, Florida.

1. Target Control Unit.

The target control unit has been completed and tested in the laboratory. Figure 6 shows the assembled unit before installation of the watertight covers which will enclose the electro-mechanical controls and data take-off system. Figure 7 presents an enlarged view of the target inclination mechanism and the contactor wheel which produces signals for radio relay of angular position data to the camera recording oscillograph. The resulting electronic markers on the oscilloscope will indicate changes in target inclination in one-degree steps. A similar method is used to provide azimuth markers at five-degree intervals.
1. Azimuth Drive Motor
2. Azimuth Data Selsyn
3. Azimuth Limit Switches
4. Watertight Stuffing Box
5. Azimuth Drive Gears
6. Stationary Azimuth Plate
7. Rotating Azimuth Plate
8. Target Mounting Arm
9. Inclination Drive Gears

Figure 6. Target Control Unit Showing Azimuth Mechanism Below Stationary Azimuth Plate and Inclination Mechanism Above Rotating Azimuth Plate.
8. Target Mounting Arm
9. Inclination Drive Gears
10. Inclination Limit Switch Supports
11. Inclination Data Gears

12. Inclination Contactor
13. Inclination Drive Motor
14. Inclination Worm Gear Sector

Figure 7. Target Inclination Mechanism and Contactor Wheel Mounted on Rotating Azimuth Plate of Target Control Unit.
2. **Camera Recording Oscillograph.**

The design characteristics of the camera recording oscillograph were given in Progress Report No. 14. Construction of the oscillograph and its associated power supplies is now almost complete, and it is expected to be ready for movement to Panama City within a few days.

3. **Analysis of Task C Data.**

Analysis of the sphere-interference runs which were made at the Navy Mine Countermesures Station, Panama City, Florida, during the month of August at the 2300-yard range is nearing completion. In the sphere-interference runs, echo strength was measured as a function of height of the 12-inch diameter target sphere above the surface of the water. The purpose of these measurements was to obtain data on the vertical distribution of field strength close to the water surface, since the radar cross-sections of small surface targets will be affected by changes in the interference lobe structure. For the runs made during August, the heights of the first and second interference maxima and the first interference minimum were about thirty per cent lower than those predicted for a standard atmosphere. An attempt is being made to correlate these results with meteorological data obtained during the sphere-interference runs. Modified index of refraction (M-value) distributions have been calculated from the meteorological data, and interference lobe patterns may be derived from the M-curves. Predicted results based on the meteorological data
will be compared with the observed echo strengths for various heights of the sphere. Rough calculations indicate that there will be fairly close agreement between the predicted and observed results.

4. Comparison of 0.87-cm and 1.25-cm Bands.

A study is being made of the expected performance characteristics at a wavelength of 0.87 cm as compared to the presently used 1.25 cm. A report summarizing the results of this study will be submitted in the near future. The report will include data on absorption and back-scattering by rain, absorption by fog, and atmospheric absorption (by water vapor and oxygen).

C. Task D - Small Surface Target Tracking.

Work on Task D has been postponed, awaiting further tests under Task C and availability of suitable equipment for radar tracking of small surface targets.

D. Personnel Changes.

Two additional members were added to the present staff during the month of November 1948.

1. Personnel Additions.

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Duties</th>
<th>Experience and Qualifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. M. Cooksey</td>
<td>Research Assistant</td>
<td>B.S. in Industrial Management, Georgia Tech; Photographic Laboratory Supervisor in Army during war; Commercial Photographer for three years.</td>
</tr>
<tr>
<td>W. E. Hollis</td>
<td>Technician (General Laboratory Assistant)</td>
<td>Sophomore in M.E. at Georgia Tech; Water Tender 3rd Class in U.S. Navy during war.</td>
</tr>
</tbody>
</table>
IV. OUTLINE OF WORK FOR DECEMBER

1) Completion of work on antenna pedestal, including wiring.
2) Completion of antenna pattern measurements.
3) Installation of FEAR on truck.
4) Continuation of tests and improvements on Control-Indicator Console and Photographic Recording Indicator.
5) Photographic tests with radar indicators.
6) Construction and test of laboratory model of computer.
7) Completion of equipment for photographic recording of small surface target echo patterns.
8) Measurements of small surface target echo patterns using the continuous film-motion technique.
9) Preparation of report on advantages of 0.87 cm band as compared to 1.25 cm band.

Approved:

J. E. Boyd,
Project Director

W. J. Muller,
Project Administrator

Gerald A. Rosselot,
Director
PROGRESS REPORT NO.17
PROJECT NO. 124-27

CONTRACT NO. NORD 10020

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and
W. J. MILLER

DECEMBER 31, 1948
PROGRESS REPORT NO. 17
PROJECT NO. 124-27

CONTRACT NO. NORD 10020

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and
W. J. MILLER

DECEMBER 31, 1948
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I. SUMMARY

During December, 1948, the State Engineering Experiment Station, Georgia Institute of Technology, continued the development of a Firing Error Analysis Radar (FEAR) under Task B of Contract NOrd 10020. The field pattern of the FEAR Rapid Scan Antenna was measured and found to be well within the designed limits; the beam width is 0.65 degree in the horizontal plane and 3.5 degrees in the vertical plane for all three reflectors in the rotating assembly. Tests and adjustments were continued on the major components of the radar system; and the FEAR Antenna, Control-Indicator Console, Photographic Recording Indicator, and Junction Box were mounted in a special body on a truck chassis to form a mobile unit.

Work under Task C consisted of limited field activities at the Navy Mine Countermeasures Station, Panama City, Florida, theoretical studies of the reflection pattern of a cylinder on a conducting plane, and analysis of interference patterns. Field operations were unsuccessful for a variety of reasons, including bad weather and equipment failures.

A frequency comparison study was made to determine the relative advantages of the 0.87-cm, 1.25-cm, and 1.87-cm wave lengths in radar tracking of small surface targets. It appears that 0.87-cm is superior to the other wave lengths for this application.

Work under Task D still awaits suitable equipment and completion of further tests under Task C.
II. INTRODUCTION

The general objectives of the work in progress under Contract NOrd 10020 are as follows: (Task A, a theoretical and experimental study of the requirements for rapid and accurate analysis of firing errors, was completed in June, 1948, and a final report (Technical Report No. 4, June, 1948) on that phase of the project has been submitted.)

Task B: Modifications of Existing Equipment and/or Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of the Order of Magnitude of 5000 sq. cm. of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments Including Possible Minor Modifications of Such Equipment to Determine Their Potentialities for Effective Tracking of Small Surface Targets.
A. Task B - Firing Error Analysis Radar (FEAR)

1. Radar System Testing, Adjustment, and Integration

During the month of December, 1948, work on the radar system consisted of a continuation of: laboratory testing, adjustment, refinement, and integration of the various units of the FEAR system; and installation of the major system units in a motor van which had been specifically prepared for this use. Tests, integration, and adjustment will be continued after the equipment is installed in the van, for a considerable portion of the month of January, 1949. Upon completion of this work the FEAR will be mobile and will carry with it radar servicing facilities and a reasonable allowance of spare parts.

2. Control-Indicator Console

As reported in Progress Report No. 16, the construction and assembly of the FEAR Control-Indicator Console has been completed. This unit underwent numerous laboratory tests and minor improvements during the early part of December and was installed on shock mountings in the van during the latter part of that month.

3. Photographic Recording Indicator

The Photographic Recording Indicator which was designed for use with the DuMont Type 314 Oscillograph Recording Camera was also tested, integrated into the system, and shock mounted in the van.

4. Junction Box

The Junction Box, reported as completed in Progress Report No. 16, was further refined and tested, and was mounted on the FEAR Rapid Scan Antenna pedestal.
5. Rapid Scan Antenna

The FEAR Rapid Scan Antenna, also reported as completed, was the subject of field-pattern measurement tests early in December.

Figure 1 shows the antenna mounted on its pedestal at the test site near the State Engineering Experiment Station. The receiving tower, which was described in Progress Report No. 16, may be seen in the background of Figure 1. Figure 2 is a closer view of the receiving tower, in which the mounting of the microwave-horn receiving antenna can be observed at the top of the tower. Field-strength measuring equipment, built in the laboratories at the State Engineering Experiment Station, is mounted on the large platform near the top of the tower.

Two closer views of the antenna and transmitting equipment, in position for horizontal field-pattern measurements, are presented in Figures 3 and 4. In Figures 5 and 6, the antenna may be seen removed from its regular mounting and placed upon an improvised turntable which was designed to permit measurement of the vertical field pattern.

In the measurements of the horizontal beam pattern, the antenna was rotated in small steps over a wide angular interval on either side of the "maximum signal" point. Comparative readings (in db) of power received at the tower were recorded for each position. Data of this nature were taken in several runs on each of the three reflectors of the antenna. During these runs, the received signal was maximized by adjusting the antenna slightly in elevation, i.e., observations of the horizontal pattern were made with the receiving antenna at the maximum point of the vertical pattern.
Figure 1. FEAR Rapid Scan Antenna in Position for Horizontal Beam Pattern Measurements.
Figure 2. Receiving Tower for Antenna Beam Pattern Measurements—Horn Mounted above Platform.
Figure 3. FEAR Rapid Scan Antenna with Auxiliary Equipment for Beam Pattern Measurements.
1. Horn Feed  
2. Horn Feed Support  
3. Wave Guide (R.F. Switch to Horn)  
4. Pulley for Motor Drive

Figure 4. FEAR Rapid Scan Antenna, Pedestal, Klystron Transmitter, and Power Supply, during Antenna Beam Pattern Tests.
1. Wave Guide (Power to R.F. Switch)
2. Power Supply
4. Signal Generator and Wave Meter

Figure 5. FEAR Rapid Scan Antenna Mounted on Turntable for Vertical Beam Pattern Measurements.
Figure 6. FEAR Rapid Scan Antenna with Auxiliary Equipment for Vertical Beam Pattern Measurements.
The transmitted signal level was kept steady by comparing it with the output of a calibrated signal generator. The angle of orientation of the antenna was measured by means of a long pointer, geared to the antenna, which moved over a large calibrated scale. The gear ratio was six-to-one, thus providing a sixfold magnification of the antenna rotation. The accuracy of angle measurements in obtaining the horizontal field pattern is estimated to be ± 0.05 degree, and the accuracy of signal-strength measurement, ± 1 db.

Results of the several runs on each reflector were normalized with respect to beam maxima and were plotted in the form of curves of field strength vs. antenna angle of rotation relative to the pattern maximum point. A composite curve which takes into account all of the data for the three reflectors is presented in Figure 7. Differences between the composite curve and the curves for the individual reflectors were within the limits of accuracy of the measurements.

Tests conducted to obtain the vertical beam pattern of the FEAR Rapid Scan Antenna were similar to those described above for the horizontal pattern, except that the antenna was mounted as shown in Figures 5 and 6 and was rotated with the turntable. A composite curve of vertical beam pattern for the three reflectors is presented in Figure 8. The measurements of the angle of orientation were obtained to an accuracy of ± 0.1 degree by means of a vernier scale on the periphery of the turntable. Again, differences between the composite curve shown in Figure 8 and those obtained for the individual reflectors were within the limits of accuracy of the measurements.

In all of the tests described above, coordination between the
Figure 7. Horizontal Beam Pattern of FEAR Antenna.
Figure 8. Vertical Beam Pattern of FEAR Antenna.
transmitting station and the receiving tower was maintained by the use of "sound-powered" field telephones.

As shown by the curves of Figures 7 and 8, the FEAR Antenna has a horizontal beam width of 0.65 degree and a vertical beam width of 3.5 degrees (angular separation of half-power, or 3-db, points on the patterns). These values compare favorably with the 0.8-degree horizontal and 5-degree vertical beam widths predicted in Technical Report No. 1, June, 1948.

6. Miscellaneous Work Items

Considerable effort was expended in equipping the motor van and in preparing it for installation of the radar equipment. The van has a special body, consisting of an enclosed operating space immediately behind the driver's cab and an open platform at the rear of the truck. The Control-Indicator Console, the Photographic Recording Indicator, a bench on which maintenance and repair work can be performed, and spare-parts storage cabinets are mounted in the enclosed operating space. The antenna with its mount and driving mechanism, the modulator, the microwave transmitter, the microwave section of the receiving system, and the junction box are mounted on the open section behind the operator's compartment. Power will be supplied by gasoline-engine-driven auxiliary equipment located in a trailer, which will be towed by the van.

Means for leveling the antenna and for reducing vibration have been provided in the form of jacks which will support the weight of the truck body when the equipment is in use. Forced ventilation has been installed where necessary, for satisfactory operation of equipment and for the comfort of operating personnel.
Progress Report No. 17, Project No. 124-27

The complete FEAR installation will form a mobile laboratory capable of operating in a spot remote from existing electrical power supplies. It is anticipated that the FEAR will be ready to proceed to the Gulf Coast by the end of January, and that splash observations can be started by February 15, 1949, as scheduled.

B. Task C - Reflecting Properties of Small Surface Targets

Investigation of the reflecting properties of small surface targets was continued along several relatively independent channels. Construction of the equipment required for field tests was completed, and the various units were moved to the Navy Mine Countermeasures Station (NMCS), Panama City, Florida, where further preparations were made for measurement of the reflection patterns of cylinders over the sea surface. Detailed theoretical studies of the reflection patterns of a cylinder in free space and over a perfectly conducting plane surface were undertaken during December, and analysis of the effects of atmospheric refraction on interference patterns close to the water surface was continued. Finally, a frequency-comparison study was made to determine the relative advantages of the 0.87-cm, 1.25-cm, and 1.87-cm bands as applied to the problem of tracking small targets.

1. Experimental Progress

Early in December, construction work was completed on the camera recording oscillograph and auxiliary apparatus required for the continuous film-motion technique of taking cylinder reflection patterns. This equipment and the target-control unit described in earlier progress reports were moved to the Navy Mine Countermeasures Station, Panama City, Florida, for
commencement of operations.

Prior to emplacement in St. Andrews Bay, the target-control unit was thoroughly tested for water-tightness and under-water operation in an experimental basin at NMCS. Figure 9 presents a photograph of the target control device during the water-tightness tests, and Figure 10 shows the unit ready for emplacement in St. Andrews Bay. A suitable target site for initial tests was located at a range of about 1200 yards from the radar position on shore.

Considerable difficulty was experienced with the operation of the AN/TPQ-2 radar because of component failures. As a result, only preliminary checking runs were made, and operations were suspended on December 22, 1948. Analysis of the scope photographs obtained indicates that troubles still exist in the radar. One item of considerable concern is the present small reserve of 3J21 magnetrons for the AN/TPQ-2. Since the life expectancy of the 3J21 is short, it may be necessary to modify the radar transmitter for use either with a 3J31 magnetron or with some other type which is available in quantity. Laboratory checks are now being made to determine the practicability of changing the type of magnetron. It is anticipated that the radar equipment difficulties will be surmounted and that operations at Panama City will recommence not later than January 15, 1949.

2. Theoretical Studies

Radar cross-section formulas have been derived for two special cases of a tilted cylinder on a perfectly conducting plane surface. One case gives the radar cross-section of the cylinder as a function of tilt along the radar line of sight (tilt toward or away from the radar). The
Figure 9. Target Control Unit Under Test for Water-tightness.
Figure 10. Target Control Unit Ready for Emplacement in St. Andrews Bay.
other case gives the radar cross-section as a function of transverse tilt (across the radar line of sight). Curves are being prepared from these formulas for values of the parameters corresponding to the anticipated experimental setups. In addition, a generalized formula is being derived, i.e., for a cylinder tilted in any direction whatsoever over a perfectly conducting surface.

3. Interference Lobe Pattern Analysis

Further studies were made of the effects of atmospheric refraction on the lobe structure of interference patterns close to the water's surface. Apparently, "lobe compression" is caused by the increasing optical density of the atmosphere with decreasing height, a result of the greater water-vapor density near the surface. Calculations of the compression of the peak of the first interference lobe are being made for index of refraction distributions derived from the meteorological data recorded during the interference runs. Rough agreement has been obtained between the lobe heights observed and the heights predicted from the meteorological data, but it is expected that closer correlation will result from more refined data analysis and calculations now underway.

In connection with the interference lobe pattern analysis, the theoretical peak return from the 12-inch diameter sphere has been calculated, using the free space return from the standard target as a reference. For a series of three sphere-interference runs made on August 26, 1948, the theoretical and experimental returns differ by approximately one decibel. This close agreement, well within the limits of accuracy of the experimental data, is considered strong evidence for the reliability of the
methods of measurement. It further indicates that the reflection coefficient of the water's surface was approximately 100 per cent at a grazing angle of about three mils, under the relatively calm sea conditions (waves about two inches high) existing during the measurements.

1. Comparison of 0.87-cm, 1.25-cm, and 1.87-cm Bands

Findings of a preliminary study on the relative advantages of the 0.87-cm, 1.25-cm, and 1.87-cm wavelength bands are as follows:

(1) The "critical range" at which the eighth power region (far zone) begins, varies inversely as the wavelength. For an antenna height of 25 feet and a target height of 4 feet, the critical ranges are approximately 7300 yards, 5100 yards, and 3400 yards for 0.87 cm, 1.25 cm, and 1.87 cm, respectively.

(2) Other factors being equal, the power return from a target in the far zone varies inversely as the sixth power of the wavelength. When other known variables are considered—including reduced power output* for oscillators operating at shorter wavelength, and increased radar cross-sections of targets# for shorter wavelengths—it is estimated that the power return from a small surface target will vary inversely as the fourth to sixth power of the wavelength, if the antenna aperture is the same for

---

* It is assumed that the power output capabilities of microwave oscillators are directly proportional to the wavelength squared.

# The maximum radar cross-sections of flat plates and corner reflectors are inversely proportional to the wavelength squared. The maximum cross-section of a cylinder is inversely proportional to the wavelength. The cross-section of a spherical target, however, is independent of wavelength.
all wave lengths. Calculations made on this basis indicate that, for small
surface targets in the far zone, 1.25-cm and 1.87-cm radars would suffer
losses of approximately 5 db and 14 db, respectively, as compared to a
0.87-cm radar.

(3) Published experimental evidence on the propagation of micro-
waves indicates that over-water radar ranges are above "standard" more fre-
quently for X-band (3 cm) than for S-band (10 cm). It appears that similar
results may hold for 0.87-cm as compared to the longer wave lengths con-
sidered in this study, but probably to a lesser degree.

(4) Attenuation by oxygen and water vapor absorption is approxi-
mately half as great at 0.87-cm as at 1.25-cm. Table I presents compara-
tive attenuation values for the three wave lengths under consideration.

<table>
<thead>
<tr>
<th>Wave length in cm</th>
<th>0.87</th>
<th>1.25</th>
<th>1.87</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attenuation in db per Nautical Mile (Two-Way) for Given Water Vapor Density, d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d = 10 gm/m³</td>
<td>0.4</td>
<td>0.8</td>
<td>0.1</td>
</tr>
<tr>
<td>d = 20 gm/m³</td>
<td>0.8</td>
<td>1.6</td>
<td>0.3</td>
</tr>
<tr>
<td>d = 40 gm/m³</td>
<td>1.9</td>
<td>3.3</td>
<td>0.8</td>
</tr>
</tbody>
</table>

(Vapor densities as high as 50 gm/m³ have been observed in tropical
regions.) From considerations of attenuation by atmospheric oxygen and
water vapor alone, the 1.87-cm wave length is far superior to both shorter
wave lengths. However, it should be noted that the 0.87-cm band suffers
much less attenuation than does the 1.25-cm band now in use.

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(5) Total attenuation by atmospheric oxygen, water vapor, and fog also is somewhat less at 0.87-cm than at 1.25-cm, unless the fog is extremely dense. Table II presents data for several combinations of fog and water-vapor densities.

**TABLE II**

TOTAL ATTENUATION BY ATMOSPHERIC OXYGEN, WATER VAPOR, AND FOG PER NAUTICAL MILE OF RANGE. (TWO-WAY LOSS)

<table>
<thead>
<tr>
<th>Wave Length cm</th>
<th>Attenuation in db per Nautical Mile (Two-Way) for Given Water Vapor Density, $d_1$, and Fog Density, $d_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$d_1 = 10$ gm/m$^3$</td>
</tr>
<tr>
<td>0.87</td>
<td>0.45</td>
</tr>
<tr>
<td>1.25</td>
<td>0.8</td>
</tr>
<tr>
<td>1.87</td>
<td>0.3</td>
</tr>
</tbody>
</table>

(The fog densities of 0.32 gm/m$^3$ and 0.032 gm/m$^3$ correspond to visibilities of about 400 ft and 2000 ft, respectively.) Attenuation by fog alone is greater at 0.87-cm than at 1.25-cm.

(6) Total attenuation by atmospheric oxygen, water vapor, and rain is greater at 0.87-cm than at 1.25-cm, except when the rain is very light. Table III presents data for several combinations of water vapor and rain.

**TABLE III**

TOTAL ATTENUATION BY ATMOSPHERIC OXYGEN, WATER VAPOR, AND RAIN PER NAUTICAL MILE OF RADAR RANGE. (TWO-WAY LOSS)

<table>
<thead>
<tr>
<th>Wave Length cm</th>
<th>Attenuation in db per Nautical Mile (Two-Way) for Given Water Vapor Density, $d$, and Rain Intensity $I$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$d = 10$ gm/m$^3$</td>
</tr>
<tr>
<td>0.87</td>
<td>1.2</td>
</tr>
<tr>
<td>1.25</td>
<td>1.2</td>
</tr>
<tr>
<td>1.87</td>
<td>0.3</td>
</tr>
</tbody>
</table>
For medium to heavy rainfall over the entire path of propagation it is seen that attenuation is greater at 0.87-cm than at 1.25-cm. This appears to be the only condition under which the shorter wave length is at a disadvantage as compared to K-band.

(7) When all factors are considered, including the probable increase in target cross-section with decrease in wave length, it appears that the ratio of target echo to rain echo (back-scattering from rain drops) will be approximately the same at 0.87-cm as at 1.25-cm, provided the antenna apertures are equal. Similar results may be expected to hold for the ratio of target echo to sea-clutter echo.

Theoretical and experimental information, from which the above data have been extracted, will be presented in detail in a separate report, if desired. The available evidence indicates that the 0.87-cm wave length should have the greatest advantages as a shipborne radar for tracking low-lying surface targets, under all conditions except heavy rainfall. Experimental studies involving the development of a 0.87-cm radar for search and tracking purposes are considered fully justified and highly desirable. Although attenuation by water vapor, fog, and rain is considerably less for 1.87-cm than for the other wave lengths, the critical-range and far-zone factors appear to eliminate this band as a possibility for the small surface-target application.

C. Task D - Small Surface Target Tracking

As stated in Progress Report No. 16, work on Task D has been postponed, awaiting further tests under Task C and the availability of suitable equipment for radar tracking of small surface targets. Limited
tracking tests may be conducted with the FEAR during the February-March firing operation, provided such additional tests can be made without interfering with the primary objectives of splash observation and firing error analysis.

D. Personnel Changes

Two additional members were added to the project staff during the month of December, 1948.

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Duties</th>
<th>Experience and Qualifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. F. Kent</td>
<td>Research Assistant (Data Analyst)</td>
<td>B.S. in Physics, Georgia Tech; Candidate for M.S. degree and part-time instructor in Physics; Ensight, USNR.</td>
</tr>
<tr>
<td>D. H. Rogers</td>
<td>Technical Assistant (General Laboratory Assistant)</td>
<td>Senior in Industrial Engineering; Radio Technician training, Treasure Island; ETM 2/c, USNR.</td>
</tr>
</tbody>
</table>
IV. OUTLINE OF WORK FOR JANUARY

(1) Completion of van assembly and electrical tests on entire FEAR mobile unit.

(2) Continuation of tests to determine optimum photographic techniques with the FEAR indicators.

(3) Preparation of finished drawings and instructions for servicing the FEAR.

(4) Final tests on laboratory model of computer, and preparation of drawings for construction of working model.

(5) Resumption of field measurement of patterns from small surface targets (cylinders and spheres), using improved target-control unit and continuous film-motion technique, with special attention to atmospheric effects.

(6) Completion of theoretical work on the problem of reflection from a cylinder tilted in any direction.

(7) Continuation of theoretical studies of advantages of 0.37-cm band for tracking small surface targets.

(8) Preparations for FEAR evaluation operations at Panama City, Florida.

Approved:

J. E. Boyd,
Project Director

W. J. Miller,
Project Administrator

Gerald A. Rosselot,
Director
PROGRESS REPORT NO. 18
PROJECT NO. 124-27

TASK A - ANALYSIS OF FIRING ERRORS

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and
W. J. MILLER

BUREAU OF ORDNANCE
CONTRACT NO. NORD 10020

JANUARY 31, 1949
TASK A - ANALYSIS OF FIRING ERRORS

TASK B - FIRING ERROR ANALYSIS RADAR

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JANUARY 31, 1949
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<td>25</td>
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</table>
I. SUMMARY

The work of the past year under Contract NOrd 10020 is reviewed. With the completion of Task A in June, 1948, Task B received major emphasis and now nears its culmination in evaluation tests of the firing error analysis radar (FEAR), which are scheduled to commence on or about February 15, 1949. A considerable amount of effort was also devoted to Task C during 1948.

The principal experimental accomplishment on this assignment has been the development of improved methods of recording the radar reflection patterns from small surface targets. Little could be done on the tracking problem designated as Task D, owing to lack of suitable equipment. It now appears unlikely that extensive experimental tracking studies can be undertaken within the time limits of the present contract.

During January, 1949, integration and testing of the FEAR in its service van was completed. At the end of the month the equipment left Georgia Tech for final readying at the Navy Mine Countermeasures Station, Panama City, Florida, prior to commencement of evaluation tests with actual firings on the Gulf of Mexico.

Under Task C, in January, the first series of experimental runs with the new target-control and echo-recording equipment was performed, using a cylinder target. The results are now being compared with theoretical curves.
II. REVIEW OF PROGRESS DURING 1948

The State Engineering Experiment Station, Georgia Institute of Technology, began work on Contract NOrd 10020 in July 1947, with the following task assignments:

Task A: Theoretical and Experimental Study of the Requirements for Rapid and Accurate Analysis of Firing Errors.

Task B: Modifications of Existing Equipment and/or Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of the Order of Magnitude of 5000 sq. cm. of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments Including Possible Minor Modification of Such Equipment to Determine their Potentialities for Effective Tracking of Small Surface Targets.

Project 124-27 was established at the Experiment Station to carry out the above task assignments. During the preliminary planning period, it was decided to submit progress reports monthly and, in addition, to submit technical reports whenever a sufficient quantity of significant material had been accumulated to justify them. This program was rigidly adhered to, except that, with the specific approval of the Bureau of Ordnance, reports for the months of June and July, 1948, were combined in Progress Report No. 12, dated July 31, 1948.
During the summer of 1947, theoretical studies of the requirements for rapid and accurate analysis of firing errors by radar were made, and the results were submitted as Technical Report No. 1 in November of that year. Additional theoretical studies initiated in the early stages of the project involved an analysis of firing data from fleet radar spotting tests, which were made available by the Bureau of Ordnance.

Progress Report No. 7, dated January 31, 1948, presented a review of accomplishments for the first six months of the contract period, which included, besides the theoretical work previously mentioned: equipping of laboratories at Georgia Tech, assembly and design of test equipment, mounting of the AN/TPQ-2 radar in a K-60 van, and field tests of the AN/TPQ-2 equipment at the Naval Air Station, Atlanta, Georgia.

In January, 1948, a field research unit was organized and dispatched to the Navy Mine Countermeasures Station (USNMCS), Panama City, Florida, taking with it the mobile AN/TPQ-2 equipment. Preliminary over-water observations of targets were conducted, using fixed targets mounted on concrete blocks in the shallow water of St. Andrew Bay. The specific aims of these tests were to verify the performance of the AN/TPQ-2 as determined at the Naval Air Station, and to establish a suitable location for later reflection measurements under Task C of the contract.

In February, 1948, the mobile radar unit was moved to St. Joseph Spit, on the Gulf of Mexico, near the town of Port St. Joe, Florida, and an experimental study of radar reflections from 5"-projectile splashes was undertaken. This operation was one of major importance to the project and involved considerable logistic effort, as the location of the test site
was remote from populated areas, conventional power supply, etc. The firings were provided by the U. S. S. RODMAN (DMS 21). Upon completion of the splash observation tests, the mobile radar was returned to its previous location at USNMCS, and the photographic records of radar indications of splashes were brought to Georgia Tech for processing and analysis.

During March, April, and May, 1948, analysis of the Port St. Joe data was performed at Georgia Tech, and experimental studies of the reflecting properties of small objects were carried on at USNMCS. An experimental 1-band radar was assembled from parts of the Mark 22 and Mark 13 systems and from other components constructed in the laboratory at Georgia Tech. This second radar was set up near the AN/TPQ-2 (K-band) equipment, with the objective of making comparisons between reflections from small objects at the two wave lengths. Considerable difficulty was experienced in keeping the X-band equipment in operation. Furthermore, correlation of the data obtained with the two systems was seriously hampered by the dissimilarities existing between their pulse and beam-width characteristics. The X-band phase of the project was eventually abandoned, as it was not considered worthwhile to embark upon a program of complete modification of an existing X-band radar, which would necessarily involve development of a satisfactory antenna also, for use at that wave length. Moreover, results of other experimental and theoretical studies indicated that shorter wave lengths were more desirable for the small surface-target tracking application.

During the months of June and July, 1948, the work on Task A of the contract was completed and a final report, Technical Report No. 4, "Radar Analysis of Surface Firing Errors", was submitted. This report described
in detail the work which has been summarized above, presented conclusions, and made recommendations for the development of an experimental model of a K-band firing error analysis radar. To obtain the necessary wide angle of scan and, at the same time, achieve good resolution through the use of a narrow beam, an antenna was designed consisting of three rotating reflectors with horn feeds and a microwave switch. A preliminary single reflector model was built and tested—with favorable results. Following this success, construction of the switching apparatus and design of major components of the complete firing error analysis radar system (FEAR) were commenced.

During the remainder of 1948, major effort was devoted to the development of the FEAR equipment, under Task B of the contract. The original concept of the FEAR was one of modification of the AN/TPQ-2 system to permit splash observation with the desired area coverage and precision. However, the necessary modifications were so extensive and the number of newly designed components so great that it is more proper now to refer to the task as the development of a new radar. Progress Reports Nos. 13 to 17 inclusive contain detailed descriptions of the work as it progressed. By the end of 1948, the FEAR was completely constructed and mounted in a five-ton, ten-wheel truck on which a special body had been built, and was undergoing electrical tests, adjustments, and minor refinements at the Experiment Station.

In addition to Technical Report No. 4, mentioned above, Technical Reports Nos. 2 and 3 were submitted during 1948. These reports presented results of the analysis of data from the fleet radar spotting tests and of a literature survey on microwave radar reflections and related topics.
In January, 1948, arrangements had been made with the Bureau of Ordnance and the Naval Proving Ground, Dahlgren, Virginia, for photographs of actual splashes to be obtained with high-speed motion-picture cameras, so that studies of the physical characteristics of projectile splashes might be correlated with the radar indications recorded during the Port St. Joe firings. A fifth technical report on the subject of growth characteristics of splashes as determined from a study of those photographs was submitted in September, 1948.

Concurrently with the development of the FEAR equipment, experimental and theoretical studies under Task C of the contract were conducted at the Navy Mine Countermeasures Station site. Attempts were made to correlate the reflections received from small objects with various angles of inclination and orientation of the objects and with meteorological observations taken over the waters of St. Andrew Bay. Cylindrical and spherical shaped targets were studied, and several methods of relating the experimental results with established theory were tried. Any attempt to correlate wave propagation experiments with theoretical predictions is a major undertaking, and the work over St. Andrew Bay proved to be no exception. The number of variables involved is so great that it is extremely difficult to isolate a single phenomenon and make a careful study of it. The work under Task C during 1948, when viewed in retrospect, appears to have yielded, primarily, improvements in methods and techniques to be applied to the problem.

At the end of the year, preparations were being made to study interference patterns resulting from variations in angle of inclination of
cylindrical targets. The patterns are obtained by tilting the target at a uniform rate and making photographic recordings of the radar scope indications with a continuous film-motion camera. In previously used step-by-step signal-strength measurements of the reflections, it was never certain that some significant part of the pattern had not been missed. The continuous-tilt, continuous-recording technique is a complex one, involving transmission of the angular positions of a target via radio to the observing site, where they are inserted as markers on the continuously moving film. Markedly successful results with the new method had not been achieved at the end of 1948, but the technique showed considerable promise, and it was decided to continue efforts to improve and to exploit it.

It has not been possible to make specific experimental studies as outlined under Task D of the contract, owing to the lack of suitable "existing equipments." The AN/TPQ-2 equipment was found to be inadequate for the effective tracking of small objects, as was the X-band radar. It was decided that neither of these radars would be convertible into a satisfactory tracking radar through modifications which could properly be described as "minor." It does not appear, now, that prolonged and significant experimental studies of the tracking potentialities of the FEAR will be possible under the existing contract, since evaluation of its primary function of splash location is considered of the highest priority, and the remaining available contract time is very limited. However, data obtained from splashes and signal returns from stationary targets will be studied with a view to visualizing and realizing other potential uses of the new radar, including the tracking application. If time permits, and if it
Progress Report No. 18, Project No. 121-27

appears feasible to make brief experimental studies of the tracking potentialities of the equipment, these will be undertaken.

In December, 1948, arrangements were made to conduct evaluation tests of the FEAR on the Gulf of Mexico at a point about 20 miles west of the Navy Mine Countermeasures Station. These tests are scheduled to take place in February and March, 1949.
III. PROGRESS DURING JANUARY, 1949

1. Task B - Firing Error Analysis Radar (FEAR)

   1. Radar System Testing, Adjustment, and Integration

      During the month of January, 1949, the FEAR testing, integration, and adjustment process, which has been described in previous progress reports, was completed. Spare parts necessary for the operation of the equipment over a period of about two months were collected and placed in the special van which carries the FEAR equipment, and the entire assembly was secured for removal to the site of its evaluation tests. Photographs of the completed installation, taken prior to its departure from Georgia Tech, are presented in Figures 1 to 7.

      Figure 1 shows the arrangement of the Antenna Unit and the operator's shelter on the rear of the van. The operator's compartment is, in reality, a miniature radar servicing laboratory, with space for spare parts and test equipment as well as for the shock-mounted Control-Indicator Unit and Photographic Recording Indicator. Views of different sections of the operator's compartment are shown in Figures 2, 3, and 4. Figure 5 is a close-up of the Antenna Unit taken from a position directly to the rear of the van. Figures 6 and 7 are side and rear views of the Antenna Unit with panels removed and the antenna in motion at 200 rpm.

      Figure 8 shows a scope photograph obtained with the Fairchild Type A Recording Camera mounted on the indicator contained in the Control-Indicator Console. The position of the radar near the rear of the Main Research Building at Georgia Tech was not a good one for obtaining patterns, on
Figure 1. "FEAR" Equipment, Antenna Unit at Left, Operator's Shelter at Right.
Figure 2. "FEAR" Control-Indicator Console, Fairchild Type A Oscillograph-
Record Camera in Recording Position on the Cathode Ray Indicator.
Figure 3. "FEAR" Photographic Recording Indicator, DuMont Type 314 Oscillograph-Record Camera (Bearing Fairchild Nameplate) in Recording Position.
Figure 4. Interior of "FEAR" Operator's Shelter, Spare Parts Storage Space and Service Bench at Right.
Figure 5. "FEAR" Antenna Unit; Transmitter in Pedestal, Lower Center; Modulator at Left of Pedestal.
Figure 6. "FEAR" Antenna Unit, Panels Removed; Junction Box in Pedestal Below Rotating Antenna.
Figure 7. "FEAR" Equipment Undergoing Test at State Engineering Experiment Station. (Pattern Recorded at this Location Is Shown in Figure 8.)
Figure 8. Pattern of Radar Reflections, "FEAR" Control-Indicator B-Scope. (90° Scan Angle, Approximately 2000 Yards Range Coverage Interval, Scan Rate = 10/sec.)
account of the nearness of other buildings. Prominent objects whose radar reflections are seen in Figure 8 could be identified by reference to a chart of the campus and its environs. However, the picture is of interest primarily in showing the type of range and azimuth markers employed for calibrating the radar scan coverage area. There are four range markers, spaced 500 yards apart, and seven main azimuth markers, separated by 15-degree intervals. The eighth azimuth marker located near the center of the pattern and offset slightly from the center azimuth line is called the Movable Azimuth Marker. It is controlled from the Azimuth Panel on the front of the Control-Indicator Console and can be used to read directly the azimuth angle between a target and a splash, or between the target on which the pattern is centered and an estimated mean point of impact of a group of splashes. The range markers may be moved en masse by means of another control located on the Range Panel of the Control-Indicator Console.

Further discussion of the features of the FEAR equipment will not be attempted here. A list of the major and minor components of the system was presented, with commentaries, in Progress Report No. 13, dated August 31, 1948; and that list has been supplemented by illustrations and explanations of system operation in more recent reports. A complete description of the finished radar will be presented, along with working diagrams, near the time of expiration of the contract.

2. Preparations for Field Tests

Arrangements for field evaluation of the FEAR on the Gulf Coast of Florida have been completed. The tests will be performed in conjunction with the U.S.S. Hank (DD 702). The Commanding Officer and various other
individuals at the Navy Mine Countermeasures Station have cooperated to the fullest extent in making these arrangements and in providing actual assistance in getting the equipment located and the necessary targets and marker buoys properly placed in the Gulf.

The FEAR equipment left the Engineering Experiment Station on the morning of January 31, 1949, making the trip to USNMCs in one day and without incident worthy of note. It is planned for the equipment to remain there only overnight, then to proceed to the test site on the Gulf of Mexico and be readied for operations. It is estimated that the two-week period between February 1 and February 15 will be required to complete on-the-spot tests and adjustments of the FEAR; but the Field Research Unit and the equipment should be fully prepared for splash observations when the ship provided by the Navy arrives, currently scheduled for February 15, 1949.

B. Task C - Reflecting Properties of Small Surface Targets

Field operations under Task C were resumed on January 10, 1949, when the Field Research Unit returned to USNMCs. Final preparations for measurements, including calibration of the receiving and indicating systems, were completed during the following two weeks. A series of experimental runs, utilizing the new target-control unit and the photographic-recording oscilloscope, was then made with a cylinder target located at a range of about 1170 yards. The photographic results are now being analysed and compared with theoretical curves for a tilted cylinder on a conducting plane. Field operations are continuing, with preparations being made for similar runs at longer ranges.
1. K-Band Echo Patterns of a Tilting Cylinder

Figures 9, 10, and 11 illustrate the types of echo patterns recorded for a 6"-diameter cylinder at a range of 1170 yards. The length of projection of the cylinder above the water surface was about 33 inches, and the antenna height of the AN/TPQ-2 radar was approximately 22 feet, during these runs. Each echo pattern was recorded in less than a second as the cylinder was tilted at a uniform angular rate in the vertical plane containing the radar line of sight. The spacings between the bright spot indications at the lower edge of each film recording represent angular tilt intervals of one degree. Thus, it is seen that the major reflection lobe has a width of about 1.5 degrees and that the minor reflection lobes have widths of about 0.6 degree.

The dotted horizontal line near the top edge of each film strip represents the level of the signal-generator reference pulse. Figure 9 was recorded at low receiver gain, with the signal-generator pulse level corresponding to a received power of 29 decibels below a milliwatt (-29 dbm). Figures 10 and 11 were made at higher receiver gains, with the signal generator pulse levels set at -39 dbm and -49 dbm, respectively. The major-lobe signal reached saturation in all cases and was too strong for measurement of its peak value with the available power-measuring equipment. At considerably greater ranges, however, it is expected that the peak signal will be determinable, and a full experimental plot of the echo pattern can then be made.

2. Theoretical Studies

Theoretical formulas for reflections from a tilted cylinder on a
Figure 9. Echo Pattern from Tilting Cylinder, for Low Receiver Gain and Signal-Generator Pulse Level of -29 dbm.
Figure 10. Echo Pattern from Tilting Cylinder, for Medium Receiver Gain and Signal-Generator Pulse Level of -39 dbm.
Figure 11. Echo Pattern from Tilting Cylinder, for High Receiver Gain and Signal-Generator Pulse Level of -49 dbm.
perfectly conducting plane have been used in preparing predicted curves of radar cross-section as a function of tilt. The theoretical curves are plotted for conditions (i.e., cylinder dimensions, antenna elevation, and range) which closely correspond with those used in obtaining the experimental data. In this way the results may be readily compared. Exact correspondence is not expected, however, since the water surface is not a perfect plane conductor. It was also necessary to make simplifying assumptions and approximations in order to carry through the mathematical derivations, and these may contribute slight discrepancies between theoretical and experimental results.

C. Task D - Small Surface Target Tracking

Limited tracking tests will be made with the FEAR equipment during the February-March firing operation, provided these additional tests can be made without interfering with the primary objective of fall-of-shot observation.

D. Personnel Changes

Two additional members were added to the project staff during the month of January, 1949.

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Duties</th>
<th>Experience and Qualifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. N. Howard, Jr.</td>
<td>Research Assistant (Member of Field Research Unit)</td>
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</tr>
</tbody>
</table>
IV. OUTLINE OF WORK FOR FEBRUARY

(1) FEAR evaluation tests in firing operation at Panama City, Florida.

(2) Construction of computer for analysis of firing errors.

(3) Continuation of field measurement of radar reflection patterns from small surface targets.

(4) Analysis of experimental data on echo patterns from cylinders, and correlation with theoretical calculations.

Approved:

Gerald A. Rosselot, Director
State Engineering Experiment Station

J. E. Boyd, Project Director
W. J. Miller, Project Administrator
PROGRESS REPORT NO. 19
PROJECT NO. 124-27

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD

and

W. J. MILLER

BUREAU OF ORDNANCE

CONTRACT NO. NORD 10020

FEBRUARY 28, 1949
PROGRESS REPORT NO. 19
PROJECT NO. 124-27

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and
W. J. MILLER

FEBRUARY 28, 1949
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This Report Contains 28 Pages
I. SUMMARY

During February, 1949, work on Contract NOrd 10020 continued with major emphasis on field operations in the Panama City, Florida, area. The most important accomplishments were: (1) Use of the FEAR equipment in the observation of splashes from 5-inch projectiles fired into the water of the Gulf of Mexico by the USS HANK (DD702); and (2) the measurement of radar reflection patterns from small surface targets in St. Andrew Bay, near Panama City, Florida. Preliminary results are presented pictorially.
II. INTRODUCTION

The State Engineering Experiment Station, Georgia Institute of Technology, has been working on Contract NOrd 10020 since July, 1947. The contract task assignments are as follows:

Task A: Theoretical and Experimental Study of the Requirements for Rapid and Accurate Analysis of Firing Errors.

Task B: Modifications of Existing Equipment and/or Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of the Order of Magnitude of 5000 sq. cm. of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments Including Possible Minor Modification of Such Equipment to Determine their Potentialities for Effective Tracking of Small Surface Targets.

Task A has been completed, and a final report was submitted in June, 1948, recommending development of an experimental radar. This radar, designated FEAR (Firing Error Analysis Radar), has been designed and built under Task B of the contract and is now being tested and adjusted for optimum performance in surface firing operations on the Gulf Coast of Florida.

Task C has been carried on concurrently with Tasks A and B and has resulted in the development of novel methods of studying the reflecting
properties of small surface targets. Data are being collected utilizing the new methods.

Under Task D, existing available radar systems have been considered with a view to making such modifications as might permit tracking of small surface targets. However, little significant progress has been made, owing to the lack of radar equipments which could be changed easily for use in that application.

A comprehensive review of work done during 1947 and 1948 was presented in Progress Report No. 18, January 31, 1949. Miscellaneous work, including construction of a computer to be used with the FEAR equipment, and analysis of data from the measurements of reflections by small objects, has gone on at Georgia Tech during February, 1949. The most important accomplishments during February, 1949 are presented in pictorial form in the following pages.
III. PROGRESS DURING FEBRUARY, 1949

A. Task B - Firing Error Analysis Radar (FEAR)

The FEAR has been at a test site on the Gulf of Mexico about 20 miles westward from Panama City, Florida, during the entire month of February. The USS HANK (DD702) arrived, as scheduled, on February 15, 1949; firing operations began at once and continued during the remainder of the month. A Series 60 Radar Target Sled was placed in position by personnel of the Navy Mine Countermeasures Station. The firing ship anchored at various prescribed positions and placed projectiles accurately and promptly as requested. Splashes were observed with the FEAR, two different photographic systems being used to record the radar returns from the splashes, as discussed in the Final Report of Task A, Radar Analysis of Surface Firing Errors. Splashes were triangulated photographically utilizing three still-shot cameras located on a known base line along the beach near the radar.

The results of operations during February have not yet been analyzed, but from a preliminary inspection of the recordings obtained it appears that the FEAR will be very successful. Figures 1 to 14 illustrate the operation described above and present samples of the radar splash recordings.
Figure 1. FEAR Evaluation Tests. The USS HANK (DD702) is shown passing near the target sled. Radar range to sled—1500 yards. Photograph taken from beach below radar site.
Figure 2. FEAR Evaluation Tests. The mobile radar equipment is shown in operating position on the beach off the Gulf of Mexico. View from water's edge.
Figure 3. FEAR Evaluation Tests. A side view of the radar van, also showing the shore line. FEAR antenna is rotating at rate of 200 rpm. Whip antenna for communication with firing ship is seen at top rear of van.
Figure 4. FEAR Evaluation Tests. The power supply units shown are located behind the radar van, as viewed from the beach.
Figure 5. FEAR Evaluation Tests. Checking radar performance by means of external test equipment. This close-up view shows power cable connections to the van. The van is supported on the heavy stabilizing jacks seen at rear.
Figure 6. FEAR Evaluation Tests. View of interior of van during the operations. Control-Indicator Console at left; Photographic Recording Indicator obscured by data recorder at right.
Figure 7. FEAR Evaluation Tests. One of three phototriangulation stations located along beach. All three still-shot cameras are operated simultaneously by electrical control at central station.
Figure 8. FEAR Evaluation Tests. B-scope recording of single projectile at four positions in flight. Images are approximately 0.1-second apart. See Figures 9, 10, and 11 for recordings of the splash made by this projectile. (Group III, Salvo 15.) The large blip at center represents the target sled.
Figure 9. FEAR Evaluation Tests. Still photograph of projectile splash taken from central camera station. (Group III, Salvo 15.)
Figure 10. FEAR Evaluation Tests. B-Scope recording of splash shown in Figure 9. (Group III, Salvo 15.) Target-sled blip at center.
Figure 11. FEAR Evaluation Tests. Recording of splash shown in Figure 9, taken with the Photographic Recording Indicator, which employs continuous film-motion technique. (Group III, Salvo 15.) Target-sled blip at center.
Figure 12. FEAR Evaluation Tests. Still photograph of a four-gun salvo, taken from central camera station. (Group III, Salvo 28.) Fourth splash is partially concealed by splash on the left. Ship's line of fire is from right to left in photograph.
Figure 13. FEAR Evaluation Tests. B-Scope recording of splashes shown in Figure 12. (Group III, Salvo 28.) Optimum operating conditions had not yet been established. The radar gain was here too high, causing undue blooming and consequent merging of the individual blips.
Figure 14. FEAR Evaluation Tests. Photographic Recording Indicator record of the four-gun salvo of Figure 12. (Group III, Salvo 28.) The large blip at left of the group represents two splashes. Proper relation between bias voltages and radar gain had not yet been determined.
B. Task C - Reflecting Properties of Small Surface Targets

During February, field operations under Task C of the contract were continued at the Navy Mine Countermeasures Station site. Reflection patterns from cylinders supported on a submerged target-control mount were obtained with the AN/TFQ-2 radar. The cylinders were tilted toward and away from the radar, and the resulting reflection patterns were recorded by means of the continuous film-motion technique, as described in Progress Report No. 18, January 1949, and in earlier reports.

An example of the pattern obtained from a 6-inch cylinder located at a range of 1170 yards from the radar was shown in Progress Report No. 18. Further runs were recorded during February on the 6-inch cylinder at 1170 yards, and the operation proceeded with pattern measurements from a 6-inch cylinder at 2290 yards, a 16-inch cylinder at 2290 yards, and a 16-inch cylinder at 5120 yards. Figures 15, 16, 17, and 18 show a representative run for each cylinder size and range. Composite plots of the return from runs made at a given range and with a given diameter, but with different gain settings are shown in Figures 19 and 20.

An attempt was made to study the patterns caused by varying the cylinder toward and away from the radar in "free space." An open-ended cylinder was mounted on a vertical pipe extending through a diameter at its center. By means of air jets located near the open ends, the cylinder was made to rotate at uniform speed, its longitudinal axis describing a circle in the horizontal plane.

None of the echo patterns presented exactly matches the mathematical curves drawn in an effort to predict the results. However, analysis of the
Figure 15. K-Band Radar Reflection Patterns. Cylindrical target 6 inches in diameter and 33 inches long at a range of 1170 yards from AN/TPQ-2 radar. The signal generator reference level is shown as a horizontal line near the top of each strip recording. Angle of inclination is given by the 1-degree markers (white dots at the bottoms of the strips). Right end of pattern recorded when cylinder was inclined away from radar.
Figure 16. K-Band Radar Reflection Patterns. Cylindrical target 6 inches in diameter and 29 inches long at a range of 2290 yards from AN/TRQ-2 radar. Right end of pattern recorded when cylinder was inclined away from radar.
(a) Signal generator level -29 dbm.

(b) Signal generator level -39 dbm.

(c) Signal generator level -49 dbm.

(d) Signal generator level -59 dbm.

Figure 17. K-Band Radar Reflection Patterns. Cylindrical target 16 inches in diameter and 44 inches long at a range of 2290 yards from AN/TPQ-2 radar. Right end of pattern recorded when cylinder was inclined away from radar.
Figure 18. K-Band Radar Reflection Patterns. Cylindrical target 16 inches in diameter and 42 inches long at a range of 5120 yards from AN/TPQ-2 radar. Right end of pattern recorded when cylinder was inclined away from radar.
Figure 19. K-Band Radar Reflection Pattern. Composite plot of returns from 6-inch cylinder, 33 inches long, at range of 1170 yards. The graph includes data at all three gain settings shown in Figure 15.
Figure 20. K-Band Radar Reflection Pattern. Composite plot of signal return from 16-inch cylinder, 44 inches long, at 2290 yards range. The graph includes data at first three gain settings shown in Figure 17.
Figure 21. K-Band Radar Reflection Patterns. "Free space" pattern of signal return from 
1/4-inch cylinder, 14 inches long, rotating at steady speed. Maximum signal return occurs 
at point where longitudinal axis of cylinder is perpendicular to radar beam.
field data is being continued and it is believed that the continuous-tilt, continuous film-motion method of studying variations in signal return is worthy of extensive further study. Although the technique is somewhat difficult to use, it appears that it can be applied to study other variables which are known to affect signal returns, such as sea clutter, interference lobes, etc.

C. Task D - Small Surface Target Tracking

During February, Task D remained in a deferred status. It is anticipated that limited tracking studies will be conducted with the FEAR equipment upon completion of firing operations at the Gulf of Mexico beach site.

D. Personnel Changes

1. Personnel Additions

Two additional members were added to the project staff during the month of February, 1949.

<table>
<thead>
<tr>
<th>Name</th>
<th>Title and Duties</th>
<th>Experience and Qualifications</th>
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<tbody>
<tr>
<td>Jean F. McCoy</td>
<td>Secretary (General secretarial duties, report preparation, etc.)</td>
<td>Graduate of Robert E. Lee High School, Baytown, Texas; Attended Lee Junior College; Clerk-typist at Humble Oil and Refining Co., Baytown, Texas.</td>
</tr>
<tr>
<td>Gene H. Garrett</td>
<td>Research Assistant</td>
<td>B.S. - Roanoke College, Salem, Va.; major in biology, physics, and mathematics; Chemistry laboratory assistant for two years and mathematics assistant for one year at Roanoke College; Instructor in biology and mathematics, Berry Schools, Mt. Berry, Ga.</td>
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</table>

2. Personnel Losses

Leta Smith, Secretary

Constance D. Seacord, Research Assistant
IV. OUTLINE OF WORK FOR MARCH

(1) Continuation of Evaluation Tests of FEAR.

(2) Return of FEAR equipment to Georgia Tech.

(3) Continuation of computer construction.

(4) Processing of film recordings and development of procedures for analysis of FEAR test data.

(5) Continuation of measurement and analysis of radar reflection patterns from small surface targets.

(6) Limited experimental studies under Task C and Task D, utilizing FEAR equipment.

Approved:

Gerald A. Rosselot, Director
State Engineering Experiment Station

J. E. Boyd
Project Director

W. J. Miller
Project Administrator
PROGRESS REPORT NO. 20
PROJECT NO. 124-27

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By

J. E. BOYD
and
W. J. MILLER

BURNT OF ORDNANCE
CONTRACT NO. NORD 10020

MARCH 31, 1949
GEORGIA INSTITUTE OF TECHNOLOGY
THE STATE ENGINEERING EXPERIMENT STATION
ATLANTA, GEORGIA

PROGRESS REPORT NO. 20
PROJECT NO. 124-27

TASK B - FIRING ERROR ANALYSIS RADAR

TASK C - REFLECTING PROPERTIES OF SMALL SURFACE TARGETS

AND

TASK D - SMALL SURFACE TARGET TRACKING EQUIPMENT

By
J. E. BOYD
and
W. J. MILLER

BUREAU OF ORDNANCE
CONTRACT NO. NORD 10020

MARCH 31, 1949
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During March, 1949, work on Contract NORD 10020 continued with major emphasis on field operations in the Panama City, Florida, area and on study of the results thereof. Field operations consisted of: (1) completion of firing operations for the purpose of study and evaluation of the FEAR equipment in cooperation with USS WERKS (DD701); and (2) continuation of the measurement of reflections from small surface targets in St. Andrew Bay.

When FEAR operations at Panama City were completed, the equipment was returned to Georgia Tech for overhaul and minor modifications. Other miscellaneous work continued at Georgia Tech.

Analysis of data recorded during firing operations and data recorded during the reflection measurements was begun.
II. INTRODUCTION

The State Engineering Experiment Station, Georgia Institute of Technology, has been engaged in work under Contract NOrd 10020 since July, 1947. The contract task assignments are as follows:

Task A: Theoretical and Experimental Study of the Requirements for Rapid and Accurate Analysis of Firing Errors.

Task B: Modifications of Existing Equipment and/or Development of New Equipment to Meet Recommendations Resulting from Study of Task A.

Task C: Theoretical Investigation and Analysis of Reflecting Properties of Small Surface Targets of the Order of Magnitude of 5000 sq. cm. of Reflecting Area.

Task D: Experimental Investigation of Existing Equipments Including Possible Minor Modification of Such Equipment to Determine their Potentialities for Effective Tracking of Small Surface Targets.

Task A was completed during the first year of work on the contract and a final report, Technical Report No. 4, June 30, 1948, recommended development of an experimental radar.

Under Task B, the experimental radar, designated FEAR (Firing Error Analysis Radar), was designed, constructed, mounted on wheels, and moved to a test site on the shore of the Gulf of Mexico, near Panama City, Florida. Actual operations were begun in February, 1949, the USS HANK (DD702) acting as firing ship. Splash observations were continued during
the first half of March, 1949, in the early part of which the USS WEEKS (DD701) relieved the HANK as firing ship. Very brief preliminary results of the February firings were reported in Progress Report No. 19. Preliminary results of the March firings are presented in this report.

Task C has been vigorously prosecuted concurrently with Tasks A and B, and the work has yielded novel methods of studying the reflecting properties of small surface targets. The data collection, which was started in January of 1949, was continued through part of March. Analysis of these data is in progress.

Under Task D, existing available radar systems have been examined with a view to making minor modifications which might permit tracking of small surface targets. Little significant progress has been made in this direction owing to lack of suitable existing radar equipments and because of the concentration of effort on Tasks A, B and C above.

This report concerns itself mainly with Tasks B and C.
III. PROGRESS DURING MARCH, 1949

A. Task B - Firing Error Analysis Radar (FEAR)

FEAR evaluation tests, described in the February Progress Report, were continued on the Gulf Coast of Florida during the first two weeks of March and were completed, as scheduled, on March 15, 1949. These operations are considered to have been thoroughly successful, although the results have not yet been analyzed in detail. The FEAR operated smoothly during the entire firing period, with the exception of the last two days when heavy rains caused troubles which could not be immediately corrected. Operation in rain was attempted deliberately—in spite of the fact that the equipment was a laboratory model not designed for such use—since it was considered desirable to observe performance of the K-band radar in detecting targets through rain. Splashes were seen through light rain, with gain reduced. Heavy rain prevented completely satisfactory observation of targets.

Upon completion of the firing operations on March 15, the FEAR was moved to Tyndall Field, Florida. The intention was to record patterns of the runways with planes taxiing and taking off, inasmuch as the FEAR appears to have distinct possibilities as a taxi-control radar for use in poor visibility and under light rain conditions. However, because of unfavorable weather conditions (continued heavy rain) and the rain damage to the antenna unit which had already been sustained during the beach tests, this experiment was abandoned. The FEAR was returned to Georgia Tech for overhaul and for minor modifications based on the experience.
gained during the February and March operations. This work was begun imme-
diately upon arrival of the equipment in Atlanta, March 22, 1949.

Typical results of the March firings are presented pictorially. They
prove rather conclusively that the FEAR is a high precision radar which
will scan a large angle rapidly with better accuracy and resolution than
has previously been available in wide-angle scanners.

1. Splash Observation Through Light Rain

Figure 1 shows examples of two single-gun salvos which were
observed through light rain. The rain interference can be plainly seen at
the bottom of the pattern in each case.

2. Multiple-Gun Salvos

Figures 2, 3, 4, and 5 show, in the order listed, the B-scope
record of a six-gun salvo (mean point of impact at approximately 1300 yards
from the FEAR), the Photographic Recording Indicator record of the same
salvo, and two triangulation camera photographs. This salvo was fired with
the parallax correction removed from the gun system on the USS WEEKS
(DD701), the firing ship for the March firings. Several salvos of this
type were fired, with a view to determining the resolution of the FEAR in
radar range. The range resolution tests were not conclusive inasmuch as
the projectiles refused to fall in a line extending from the radar as
desired. However, the pattern presented is typical and serves to illus-
trate the fact that in most firings where a small number of splashes are
observed the FEAR will very probably resolve them clearly in both radar
range and radar bearing. The particular salvo presented has a spread in
radar range of about 250 yards and a spread in radar azimuth of about 75
Figure 1. B-Scope Recordings, FEAR Evaluation Tests, Group XIV Firings. Target Sled in Center of both Patterns, 1,660 Yards from Radar. (A) - Salvo 3, Splash 1300 Yards from Radar; (B) - Salvo 5, Splash 2100 Yards from Radar.
Figure 2. B-Scope Recording, FEAR Evaluation Tests, Group VIII Firings, Salvo 12. Six-Gun, Target-Practice, Service-Charge Salvo, Fired at Range of 8000 Yards. Estimated M.P.I. from Radar—1300 Yards, 40 Degrees Right.
Figure 3. Photo-Indicator Recording, FEAR Evaluation Tests, Group VIII Firings, Salvo 12.
Figure 4. Still Photograph of Salvo 12, Group VIII, Taken from Camera Station 800 Yards Right of Radar.
Figure 5. Still Photograph of Salvo 12, Group VIII, Taken from Camera Station 80 Yards Right of Radar.
mils (approximately 100 yards at the range of 1300 yards). It is interesting to note that the FEAR clearly resolved six objects within the rectangle defined by the above distances and that the rectangle is largely unfilled.

Another example of a multiple-gun salvo is shown in Figures 6 to 9 inclusive. This salvo differs from the one previously shown in that the spread in firing range (and radar azimuth) is greater while the spread in deflection (and radar range) is less. The radar range spread in this case is about 110 yards while the azimuth spread as observed from the radar is 130 mils (350 yards). Again it is seen that the rectangle outlined by these distances is largely empty, showing that the FEAR is capable of handling patterns which have a much smaller spread than this one. The three splashes grouped together in the upper center portion of the pattern cover an azimuth spread of about 35 mils (95 yards). Although the blips are not resolved, the three splashes are discriminable from both types of recording. It can be said that the angular discrimination at this range is one degree (17.5 mils), the linear separation required for discrimination being, of course, proportional to the radar range. It would appear quite practical to specify the offsets in gun practices so that short radar ranges are used, thereby giving improved linear discrimination.

Referring to Figure 7 it will be noted that miscellaneous signal returns are scattered throughout a good portion of the field of coverage. There are in large measure sea echoes; on the day that this salvo was fired there was considerable wind and whitecaps were prevalent in the firing area. The extraneous returns cause no confusion, however, since the signals from the splashes form a recognizable blip pattern which is repeated over a large
Figure 6. B-Scope Recording, FEAR Evaluation Tests, Group VIII Firings, Salvo 5. Six-Gun, Target-Practice, Service-Charge Salvo, Fired at Range of 8000 Yards. Estimated M.P.I. from Radar—2650 Yards, 16 Degrees Left.
Figure 7. Photo-Indicator Recording, FEAR Evaluation Tests, Group VIII Firings, Salvo 5.
Figure 8. Still Photograph of Salvo 5, Group VIII, Taken from Camera Station 80 Yards Right of Radar.
Figure 9. Still Photograph of Salvo 5, Group VIII, Taken from Camera Station 550 Yards Left of Radar.
Progress Report No. 20, Project No. 124-27

number of frames.

3. Detection of Air Bursts and Projectiles in Flight

Since the firing ship desired to make a routine check of the sen-
sitivity of VT fuses, a test group of salvos was fired which utilized the
FEAR for this purpose. In order to compare air bursts with surface splashes,
two-gun salvos containing one inert-loaded projectile and one live VT round
were fired. A sequence of observations recorded with the Photographic Re-
cording Indicator is shown in Figure 10 and will be discussed in some detail.
Selected frames are presented in the interests of saving space and facili-
tating comparison. Each frame represents one scan of the FEAR antenna, the
time between successive scans being 0.1 second. The frames are numbered
consecutively from the first indication of the projectile or splash. Frame
0 shows only a marker buoy, a small cylinder 16 inches in diameter, project-
ing approximately three feet, ten inches from the surface of the water, at a
range of 2600 yards from the FEAR. In Frame 1, one of the projectiles has
put in its appearance, below and a little to the right of the marker buoy.
In Frame 2, the second projectile has entered the radar beam of the FEAR.
These projectiles were seen to move steadily to the left in the omitted
subsequent frames. Frame 11 shows how far they have progressed in a little
less than a second. In Frame 14, the inert-loaded projectile, which was
farther to the left, has disappeared momentarily, and the VT fused projectile
is seen in motion for the last time. Between Frames 14 and 15 the VT pro-
jectile exploded, the first results of the explosion appearing in Frame 15.
In Frame 16, the inert-loaded projectile has reappeared, still in flight,
and the results of the VT explosion have spread. It is believed that
Figure 10. Photo-Indicator, FEAR Evaluation Tests, Group X Firings, Salvo 1. Two-Gun Salvo Containing Target Practice and VT Fused Rounds, Fired at Range of 10,000 Yards with Service Charge. The VT Projectile Burst Occurs Close to the Sea Surface.
Frame 18 shows the inert-loaded projectile at the instant of impact, or the splash from this projectile at a very short time after impact, since in the succeeding frames there is no measurable further motion to the left and the blip takes on the characteristics of splash returns. Frames 20, 22, 24, and 26 show the continued spreading of the water disturbance caused by the shrapnel from the air burst, in relation to two fixed points determined by the splash from the inert-loaded projectile and the marker buoy. Figures 11 and 12 show the phototriangulation photographs of the splash from the inert-loaded projectile and the water disturbance from the air burst taken from two different camera positions. In Figure 11 the air burst is partially obscured by the sled target, which was almost on a line with and between the FEAR and the air burst but which is not shown in the FEAR pattern recordings. It is interesting to note that the 16-inch cylinder marker buoy which appears in the sequence of Figure 10 is too small to appear in the triangulation photographs.

4. Automatic Gain Control (AGC)

Considerable effort was devoted to the development of an automatic gain control device (AGC) for inclusion in the FEAR, and its performance was tested during the evaluation operations. Figure 13 shows a sequence of frames taken from successive scans of the FEAR antenna with the AGC operative. It will be recalled from the description in Technical Report No. 4, June, 1948, that the AGC reduces the radar receiver gain by an amount determined by the strength of the signals observed on one scan of the antenna and then makes this signal reduction effective on the succeeding scan. Alternate scans, therefore, represent operation at the manually
Figure 11. Still Photograph of Salvo 1, Group X, Taken from Camera Station 80 Yards Right of Radar.
Figure 12. Still Photograph of Salvo 1, Group X, Taken from Camera Station 800 Yards Right of Radar.
Figure 13. Photo-Indicator Recordings, FEAR Evaluation Tests, Group VII Firings, Salvo 17A. Manual Setting of Radar Receiver Gain High, AGC Operating on Alternate Scans (or Frames).
set value of receiver gain; the others at some different, automatically
selected gain setting. The "upsy-downsy" action is apparent in the pairs
of frames presented in Figure 13. Study of these and other recordings
made with the AGC in operation as compared to recordings in which fixed
gain for optimum resolution was employed, have indicated that little im-
provement in accuracy and resolution is to be realized by the inclusion of
the AGC circuits in the FEAR. However, since it is extremely difficult to
establish the optimum gain for a particular set of firing conditions it
may be desirable to vary the gain of the receiver in a manner which can be
manually preset or adjusted and which would be a great deal simpler to in-
clude and use. In selecting a gain setting for optimum resolution there
is a chance that the gain may be set too low and that some splashes may be
missed entirely. A second gain setting, higher than the one thought to be
optimum and effective on every other scan, would provide a safeguard
against missing splashes or observing them at such a late instant in their
growth as to have errors introduced in locating the true point of impact of
projectiles.

A simplified gain switching circuit of this type is now in pro-
cess of construction. The circuit will provide a means of employing two
previously selected gain levels on alternate scans, the switching from one
to the other level being automatic. It is believed that this simple
switching device will assure adequate accuracy and resolution and at the
same time reduce the over-all complexity of the FEAR in a considerable
amount.
5. Preliminary Estimate of FEAR Performance

Although analysis of the results of the FEAR tests has only begun, preliminary examination of the photographic recordings and brief comparison with the results of phototriangulation for a few salvos indicate that the performance of the FEAR will be as follows:

(a) Range Coverage along line of fire, ± 1000 yards;
(b) Deflection Coverage perpendicular to line of fire, ± 1000 yards;
(c) Range and Bearing Accuracy, ± 15 yards;
(d) Resolvable Impact Separation, ± 0 yards;
(e) Tow Target Distance, 1500 yards; and
(f) Towing Speed, any speed at which sled targets can be towed.

Comparison of the above values with those previously tabulated in the Final Report of Task 1, Table XII, page 187, shows that the performance of the experimental radar will fall within acceptable limits for all operational requirements and that it will give much more area coverage than that previously considered acceptable.

6. Miscellaneous Task B Work

In addition to the major effort described in the foregoing paragraphs, considerable miscellaneous work in connection with Task B has been done in the laboratories at Georgia Tech. A computer is now under construction, designed to solve for the angle between the line of fire and the tow-target line, using range and bearing of the target and of the firing ship (determined from the towing vessel) as input values. With the line of fire thus established, the computer will convert radar ranges and bearings of
splashes into gun range and deflection errors. This instrument will be useful in practice to give rapid solutions for the range and deflection errors of the estimated mean point of impact of a salvo, in terms of the radar range and bearing coordinates of this MPI as estimated by the B-scope operator. The computer is about 90% completed, and it is expected that it will be tested during April, 1949.

Overhaul and minor modifications of the FEAR were in progress by the end of the month. A general clean-up of the wiring and the RF systems is contemplated; the Junction Box is being rebuilt; the AGC system is being simplified; and minor circuit changes are being made to improve the range sweep linearity in the Photographic Recording Indicator. A comprehensive system of circuit diagrams for the FEAR is in process of preparation, and reduction of the data from the FEAR evaluation tests has been started.

B. Task C - Reflecting Properties of Small Surface Targets

1. Analysis of Cylinder Data

The preparation of a preliminary technical report covering the experimental studies of cylinder radar cross-sections has been started. At the present time the data have been collected and compiled, and representative radar cross-sections have been obtained for both 6"-dia. and 16"-dia. cylinders at various ranges.

The data are compiled so that the accuracy of the continuous recording technique of data recording can be evaluated. Figures 14 through 18 present typical results obtained when several runs for a given set of conditions are plotted together. A comparison of all the data obtained shows an average spread of approximately ± 3/4 db with a maximum deviation...
Signal Generator Level

Target: 6" dia. cyl. 30" long
Range: 2290 yds.
Azimuth: 0°
Inclination: Cont. variable
- Fast motion toward radar
• Fast motion toward radar
+ Fast motion away from radar
□ Slow motion toward radar

Figure 14. Plot of Four Runs Taken on 6" Cylinder. Signal Generator Level -39 Dbm.
Figure 15. Plot of Four Runs Taken on 6" Cylinder. Signal Generator Level -49 Dbm.

Target: 6" dia. cyl. 30" long
Range: 2290 yds.
Azimuth: 0°
Inclination: Cont. variable
- Fast motion toward radar
○ Fast motion toward radar
+ Fast motion away from radar
□ Slow motion toward radar
Figure 16. Plot of Two Runs Taken on 6" Cylinder. Signal Generator Level -59 Dbm.
Target: 16" dia. cyl. 40" long
Range: 2290 yds.
Azimuth: 0°
Inclination: Cont. variable
- Fast motion toward radar
- Fast motion toward radar
+ Fast motion away from radar
- Fast motion away from radar
Δ Fast motion away from radar

Figure 17. Plot of Five Runs Taken on 16" Cylinder. Signal Generator Level -0.9 Dbm.
Target: 16" dia. cyl. 12" long  
Range: 5120 yds.  
Azimuth: 0°  
Inclination: Cont. variable  
• Fast motion toward radar  
○ Fast motion toward radar  
△ Fast motion toward radar  
+ Fast motion away from radar  
□ Fast motion away from radar  

Figure 18. Plot of Five Runs Taken on 16" Cylinder. Signal Generator Level -59 Dbm.
of approximately ± 3 db. These results indicate that this data recording method has an inherently high degree of accuracy, particularly since the results obtained agree within the limits of experimental error.

Composite plots of the echo signal strength vs. cylinder inclination from the vertical are presented in Figures 19, 20 and 21. These curves represent the average values of several runs. The outstanding characteristic is the relative absence of side lobes in the reflection pattern. Preliminary data taken in August, 1948, revealed very pronounced side lobes, whereas data taken during February, 1949, under similar operational conditions showed very little evidence of side lobes. The only factors known to be appreciably different between the August and February runs are the meteorological conditions. This fact would indicate that meteorological effects definitely influence the reflection patterns of small surface targets.

2. Floating Cylindrical Buoy Target

The cylindrical buoy shown in Figure 22 was placed in the Gulf of Mexico and used as a target for the FEAR in tests to evaluate the reflecting characteristics of a floating object. Scope pictures of the echo from the buoy at a range of 2600 yards are presented in Figure 10. At this range the target returned a strong echo. Subsequently, heavy seas caused the buoy to drift a considerable distance from its original position. It could not be located visually, but was finally discovered at a range of 4700 yards by means of the FEAR. At that range the echo varied, with motion of the buoy, from a strong return to no return. However, a signal was visible about half the time.
Figure 19. Composite Average of Echo Strength vs. Inclination Angle for 6" Cylinder at 2290 Yards Range.
Figure 20. Composite Average of Echo Strength vs. Inclination Angle for 16" Cylinder at 2290 Yards Range.
Target: 16" dia. cyl. 42" long
Range: 5120 yds.
Azimuth: 0°
Inclination: Cont. variable

Note: Composite of average values.

Figure 21. Composite Average of Echo Strength vs. Inclination Angle for 16" Cylinder at 5120 Yards Range.
Figure 22. Cylindrical Buoy (Drawn to Scale).
Measurements of the echo strength of the cylindrical buoy as a function of time were recorded for ranges of 2550 yards and 4200 yards. Figure 23 presents a run for 4200 yards range with the signal generator set at -69 dbm. During the time these measurements were being made, the FEAR was not operating properly and operations were finally halted by failure of the FEAR, due to water damage previously sustained. The results are presented here as a matter of interest and are not to be considered indicative of the results which could be obtained under proper operating conditions.

3. Preparation of Equipment to Study Meteorological Conditions Near the Sea Surface

Analysis of data collected during the summer of 1948 revealed distortion of the vertical interference pattern near the sea surface. This effect was considered in Progress Report No. 17. Also, as discussed previously, the difference between cylinder patterns obtained during the summer and the winter months indicates that the meteorological conditions affect cylinder reflection patterns. In view of the above observations it was decided to construct the equipment necessary to collect simultaneously meteorological data and interference patterns in an attempt to determine the relationship between the meteorological conditions and propagation where the paths of propagation are within 25 feet of the sea.

Design and construction have commenced on equipment to permit rapid recording of meteorological data. The system is composed of eleven stations employing thermistors to obtain wet and dry bulb temperatures with the resulting information being recorded by an Esterline-Angus Recorder. Readings are to be taken successively with a time duration of one minute.
Figure 23. Signal Returned from Cylindrical Buoy at 4200 Yards Range over a Period of One Minute. Signal Generator Level -59 Dbm. (Sequence Reads from Right to Left and from Top to Bottom.)
being required to complete the cycle of eleven stations which are distrib-
uted between the sea surface and a height of 30 feet.

The interference patterns will be determined by continuously re-
cording the echo strength from a sphere (or corner reflector) as its height
above the sea surface is varied.

4. The Effect of Atmospheric Refraction Upon Interference Lobe
Patterns

Interference patterns representing the power return dependency
upon height of target have been plotted as a function of target height for
a 12" spherical target at a radar range of 2320 yards. It was noticed that
the maxima and minima were considerably depressed from their predicted posi-
tions. Analysis has been underway in an attempt to show that variation of
atmospheric refraction with height can account for the pattern depression.
Meteorological measurements indicate that the index of refraction often de-
creases rapidly with height in the first few feet above the water surface.

By utilizing a ray-tracing formula developed in connection with
another Georgia Tech project and a phase-difference method outlined in Navy
Radio and Sound Laboratory Report No. WP-10, 10 March 1944, ray paths have
been plotted between transmitter and target, and the resultant interference
pattern has been computed. The interference pattern thus obtained is in
reasonable agreement with the experimental data within the limits of accuracy
of the meteorological data.

Approximate analytic expressions for the phase difference between
the direct and indirect wave paths have also been derived and used in
plotting the interference lobe patterns. Results obtained by this method
are in reasonable agreement with the interference patterns which were obtained experimentally.

A complete report on the correlation of meteorological data and interference lobe pattern depression is now being prepared. The report will also include results of studies of power return from the standard sphere as a function of radar beam elevation and tide height.

C. Task D - Small Surface Target Tracking

Due to the use of available personnel on Task B and Task C work, no specific experimental studies were undertaken under Task D. However, Figure 10, which shows strong signals from a small floating cylinder used as a reference marker in the air burst observation, gives some indication that the FEAR (or a similar radar with a high scan rate, narrow beam, and short pulse length) might be effective for tracking small surface targets. It is interesting to note that the geometrical cross section of the cylinder was approximately 5000 sq. cm. Furthermore, the FEAR was able to detect and fix the position of the floating cylinder mentioned above at a range of 4700 yards without the operator making a careful search and without any knowledge of its location. This lends further support to the possible value of this type of radar for the small object search and tracking functions.

D. Personnel Changes

1. Personnel Additions

One additional member was added to the project staff during the month of March, 1949.
No. 124-27

Progress Report No. 20, Project No. 124-27

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Name: Marshall A. Lochridge, Jr.  Title and Duties: Technical Assistant (Data Analyst)

Experience and Qualifications:
Junior in Industrial Engineering with previous experience in measurement and computation work.

2. Personnel Losses

Thomas B. White, Research Assistant

(1) Continuation of analysis of radar reflection patterns from small surface targets.
(2) Continuation of unclassified and other preliminary studies.
(3) Continuation of radar propagation.
(4) Progress report for use in connection with Task B.
(5) Continuation of analysis of radar reflection patterns from small surface targets.
(6) Preparation for FMR antenna pattern measurement.
(7) Preparation of RNL reflection tests, and preparation of a report on the possibility of extending the useful life of those targets.

Y. E. Boyd
Project Director

M. R. Miller
Project Administrator

Appended:

G. A. Brennan, Director
State Engineering Experiment Station

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IV. OUTLINE OF WORK FOR APRIL

(1) Continuation of analysis of FEAR test data.

(2) Continuation of overhaul and minor modifications of FEAR.

(3) Completion of construction of FEAR computer.

(4) Construction of meteorological equipment for use in connection with Task C.

(5) Continuation of analysis of radar reflection patterns from small surface targets.

(6) Preparation for FEAR antenna pattern measurements.

(7) Continuation of 3J21 magnetron tests, and preparation of a report on the possibility of extending the useful life of these tubes.

Approved:

Gerald A. Rosselot, Director
State Engineering Experiment Station

J. E. Boyd
Project Director

W. J. Miller
Project Administrator