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NAVAL RESEARCH LABORATORY

Annual Technical Report

Fiscal Year 1948

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WASHINGTON, D.C.

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FOREWORD

The mission of the Naval Research Laboratory is to increase the safety, reliability, and efficiency of the Fleet by the application of scientific research and primary, or laboratory, experimentation to Navy problems. The work of the Laboratory embraces scientific activities which are important to present and future naval power and national security. These activities are divided into three general categories--research, development and test. The applied research, development and evaluation work is designed to meet the immediate requirements of the Navy, and is undertaken upon a request originating in the National Military Establishment and transmitted through the Chief of Naval Research or one of the materiel bureaus--Ships, Ordnance, Aeronautics. Such work is normally directed toward some immediate and recognizable need, or the test and evaluation of an existing or proposed weapon or equipment. The basic research at NRL is undertaken in anticipation of future naval needs. This work has as its objective the production of new knowledge rather than specific items of equipment: knowledge which will lead to new developments and applications. This work originates in the Laboratory and represents the judgment of its scientists as to the need for research within given areas.

These specific types of scientific endeavor are classified into nine fields of research: Chemistry, electricity, mechanics, metallurgy, nucleonics*, optics, physics, radio and sound. Into these fields fall the various research problems, approximately 600 during the fiscal year 1948, which make up the Laboratory's work program.

A detailed outline of the scientific program of the Laboratory, formulated by its Scientific Program Board, is to be found in NRL Report No. 3270 "Scientific Program of the Naval Research Laboratory" (Confidential) July 1, 1948. Detailed reports on the individual problems as carried out under this program are made, when there is significant scientific progress to discuss, in the "Report of NRL Progress" published monthly. These publications are available for those who wish to reference the program in general or to follow step by step the investigation or solving of a specific program or problem.

This annual report, the first of its kind to be issued by the Laboratory, presents by field of research the scientific accomplishments dur- the period 1 July 1947--30 June 1948. Comments on the usefulness and distribution of this document will be appreciated.

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*Extensive research in the field of Nucleonics was carried out by NRL during the 1948 fiscal year. The classification is AEC Restricted Data, and therefore a summary of the work cannot be included here.

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CHEMISTRY

FUELS (C01)

The Navy is constantly in search of new fuels with higher heats of combustion, especially as jet propellants, and studies have been underway of possible fuels other than hydrocarbons. Most promising of the inorganic fuels are the hydrides (and certain other derivatives) of the light elements, those of boron having received the greatest attention to date (C-3311, Confidential).*

Because diborane tends to decompose when stored under pressure, safe handling requires specific knowledge of its physical properties, especially near the critical point. Determinations have been made of critical temperature, critical pressure, and vapor pressures at various temperatures. Diborane compressed into cylinders to 1103 psia at 57° C decomposed at such a rate as to give a pressure of 1390 lb at the end of 5-1/2 hours. A portable apparatus for the analysis of diborane gas has been built and operated to determine its adequacy.

A study of the conversion of diborane to pentaborane is continuing together with an investigation of three methods for the production of aluminum borohydride. Small samples of pentaborane and of aluminum borohydride have been forwarded to Navy contractors for evaluation of their thermochemical properties.

Dr. H. I. Schlesinger and associates at the University of Chicago are proceeding with their basic studies of compounds of the light elements. Their quarterly reports (C-3107, C-3147, C-3208, all Unclassified) gave results on a sodium aluminum hydride preparation in tetrahydrofuran in which there was obtained a 70 percent yield of material showing 92 percent purity. Also reported are studies on the preparation of borazole (together with some work on its stability) and preliminary steps in the production of other boron-nitrogen-hydrogen compounds.

From the broadened knowledge in this field, it is hoped that improved high-energy propellants will be developed. Mine Safety Appliances Company has produced about 140 lbs of diborane which has been distributed to various organizations working under Navy and Army contracts. Among these are the General Electric Company, NACA, Reaction Motors, Applied Physics Laboratory, Bureau of Standards, Ohio State University, and Cornell University.

Synthesis of pure hydrocarbons in the Diesel range is continuing satisfactorily, and methods for the laboratory evaluation of these fuels are under investigation.

Much work has been done to determine the applicability of spectroscopic methods of analysis to fuels and lubricants and to the determination of molecular structure of their constituents.

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* NRL reports prepared during the fiscal year 1948 which are pertinent to the research discussed in this annual report are listed by field in Appendix A.

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The infrared and ultraviolet absorption spectra of a large number and variety of pure hydrocarbons are being determined (C-3274, Unclassified) in order to obtain a correlation with molecular structure and physical properties. Such data may be used: (1) to identify compounds of unknown structure; (2) to determine qualitatively the components present in mixtures; and (3) to analyze quantitatively mixtures of from two to twelve components.

While the systematic study of high-purity hydrocarbons has been limited largely by the availability of samples, during the last four years a collection of over 250 specimens has been obtained from projects sponsored by the American Petroleum Institute and from various university laboratories. Of these samples, all of the paraffins as well as certain groups of aromatic and olefinic hydrocarbons have now been studied over the 2- to 22-micron range using the NRL 3-prism infrared spectrophotometer. Altogether, 125 of these reference spectra have been collected (C-3274, Unclassified).

Correlation of the spectral data with molecular structure shows that some spectral absorptions are characteristic of a general class or type of compound. Others are characteristic of a particular molecular grouping, and still others appear to be typical of the particular molecule in question rather than of any type of group of molecules in general. Those which characterize a molecular grouping are of especial interest since they are neither too general nor too specific to be of practical use.

LUBRICANTS (C02)

Naval requirements for lubricants demand a particularly wide range of operating service temperatures from the very high (such as in turbo-jet engines and high-speed, totally enclosed electric motors) to the very low (such as encountered in the sub-zero Arctic winters). In addition, nonflammable oils and greases are required for numerous applications, while aeronautical instruments call for nonspreading oils of favorable viscosity/temperature characteristics. In all of these fields, significant progress has been made during the past year.

Not the least important development in the Lubricants program has been the systematic study of hydraulic fluids in search of satisfactory replacements for the usual flammable materials based on petroleum or castor oil (P-2944, P-3020, both Unclassified). In exhaustive tests, the recently developed Hydrolubes, especially Hydrolube U-4, showed great superiority over other candidate materials such as halogenated hydrocarbons (C-3284, Unclassified) and the silicones. Pressures up to 3000 psi are operable in hydraulic systems based on the Hydrolubes.

Work in the field of high-temperature greases has been aimed at a service life of 4000 hours at temperatures of 450° F or higher. This is considerably beyond the performance of the customary petroleum-based greases, application of which is greatly limited by thermal and oxidative deterioration. An ordinary grease is composed of a liquid lubricant gelled with a metallic soap. When hydrocarbon lubricants are replaced by halogenated compounds, diesters, polyethyleneglycols, or some of the silicone oils, the soap becomes the limiting factor. It undergoes a complex series of phase changes and loses its gelling power at about 325° F. Even the oxidation inhibitors used in conventional greases are themselves often quickly destroyed at or about this temperature.

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While much work has continued to extend fundamental knowledge of the properties of various types of lubricants, a radically new approach was made to the problem of high-temperature greases. Based on entirely novel principles and especially adapted for high-temperature lubrication, a new type grease has been developed. Thus far tests have been extremely favorable. In the new greases no soap is used, its place being taken by a class of organic compounds heretofore unknown in the lubrication field. These maintain their gelling properties up to 500° F and thus offer a new range of lubrication possibilities, the extent of which has not yet been fully explored. It is believed that the new compositions will soon be made available for service-simulating tests by other Naval activities.

Relationship of particle size and shape of the gelling agent used to the physical properties of greases has been investigated by use of the ultramicroscope and the electron microscope.

Since oxidative degeneration of lubricants at the higher temperatures is still a major problem, much emphasis has been placed on a fundamental study of the oxidation reactions and the mechanism by which oxidation inhibitors function. A vigorous search is underway for better inhibitors for high-temperature lubricants.

A new program has been initiated for the study of fundamental phenomena in friction and wear as related to lubrication. Nearing completion is a Bowdon stick-slip machine to be applied to the study of boundary friction and the lubrication properties of monolayers, and the Shell 4-ball machines are also being used for the study of wear. With the aid of these devices it is proposed to concentrate on the study of the lubricating properties of hydrolubes, silicones, and the halogenated hydrocarbons as well as the usual synthetic lubricants and greases. Bearing metals will form an important part of this study since there is an urgent need for better high-temperature-resisting ball bearings for the silicone-wound motors and for the new high-speed gyroscopes.

Some special attention has been afforded the silicones, which were recognized early during the war as possible lubricants where conventional petroleum products proved unsatisfactory. Use of the silicones under conditions of high temperature requires adequate knowledge of their thermal and oxidative stability and of their products of oxidation.

An investigation of the thermal and oxidative stabilities of polymethylsiloxanes of several viscosities showed these fluids resisted oxidation up to 200° C. Above this temperature, the methyl groups are ruptured and oxidized to formaldehyde and formic acid. Condensation of two or more residues causes an increase in viscosity, and these increases are found to be valuable criteria of oxidation stability (C-3118, C-3192, both Unclassified). The phenyl methyl siloxanes are more resistant to oxidation, being stable up to 225° C, but have somewhat less desirable temperature/viscosity characteristics.

During the wartime search for rust inhibitors, investigations were made into the possibilities of certain aryl-substituted fatty acids, and the arylstearic acids and their salts were found especially promising (C-3251, Unclassified). Recent syntheses extend the hydrogenation of the aryl-substituted aliphatic acids to molecules with a longer aliphatic chain and (in some cases) with a more complex aromatic component.

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Improved test methods for evaluating rust inhibitors have been evolved (C-3100, Unclassified). Data gathered at NRL should put the whole subject on a systematic foundation and eliminate a great deal of wasted industrial effort in the synthesis and testing of new materials for the purpose.

In the field of crankcase lubes for sub-zero, Arctic use, many useful correlations have been collected on the diluent effect of the aliphatic diesters on a number of natural and synthetic oils (C-3273, Unclassified). While the diesters are ineffective as pour-point depressants for paraffin-base oils, they are useful with the synthetic polyalkylene glycol polyethylene oils, polyglycol ethers such as "Ucon" fluids, and with napthene-base petroleum oils. Although not as efficient as gasoline, the diesters have the advantage of permanency, reduce the fire hazard, and in some cases improve the viscosity index.

No more than initial steps have been taken toward the production of satisfactory synthetic, nonspreading oils for use in aircraft instruments. Instrument oils must be stable to heat and oxidation, must be noncorrosive, must have very low vapor pressures and high viscosity indices, and, finally, must not spread away from a pivot or bearing to contaminate adjacent parts or allow the bearing to run dry. The literature and patents on this characteristic show that the nonspreading property is not well understood and that suitable instrument oils are developed only by tedious evaluation of many candidate oils.

PROTECTIVE SURFACES (C03)

It has long been known that attack by fungi is a principal cause of the rapid deterioration of materials in tropical environment, and in recent years the potentialities of certain classes of organic compounds in fungus control have been recognized. Recent activities in organic synthesis have resulted in the systematic preparation of several series of compounds, of which a number of the individual members are wholly new. Synthetic work in this field is continuing with the purpose of correlating organic structure with fungicidal activity, and the first phase of a comprehensive mycological evaluation has been completed with the examination of approximately 1000 compounds (C-3114, C-3289, both Unclassified).

Various α-bromoacetanilides studied previously proved extremely toxic to fungi, whereas unhalogenated amides and monohalogenated paraffins were found to have no fungicidal activity. Because their structure is analogous to that of the α-bromoacetanilides, it was decided to attempt the preparation of a large number of N-alkyl- α-bromoamides (C-3326, Unclassified). Subsequent fungicidal evaluation gave highly promising results, especially for the α-bromoacetanilides, which were found to possess high fungicidal value with low toxicity to man. The α-bromopropionamides, on the other hand, showed diminished fungicidal value, thus indicating (by extrapolation) a decrease in activity with increase in length of the carbon chain.

The Tropical Deterioration Station at Fort Sherman, Canal Zone, has been very active in the conduct of actual field tests with the new fungicidal materials as well as in tests of general deterioration under exposure to the ravages of the tropical climate (C-3073, Unclassified). Besides its investigations for NRL, the Station has also undertaken special jobs for other Navy groups and for the Army. Currently on exposure at the Station are samples of a dozen or more Navy Communication Receivers of four

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types together with a variety of toxic coating materials from NRL and about 500 paint specimens from other branches of the armed forces. Exposure and observation of a large number of aircraft fabrics is in process and a series of experiments have been undertaken on the behavior of plastics under tropical conditions. In cooperation with the Navy Department a study of the micro-flora of the region is being made, and facilities at the Station are being expanded to accommodate the increased workload.

Included in the protective surfaces program is continuing work on barnacle-repellent finishes and on protective anodes for ships' hulls. In the latter, results have been reported on a series of experiments to clarify the anodic behavior of aluminum-zinc and zinc alloys. This work verified previous results showing that high-purity zinc anodes are most effective for the protection of steel in sea water. A modified design for the pure zinc anode has been recommended (C-3277, Unclassified).

In the field of antifouling paints (C-3163, Unclassified) experiments have shown that the efficiency of the copper-bearing film may be increased by the addition of fillers or inert pigments. This is thought to be due to increased film porosity, which provides a more favorable leaching rate for the copper pigment.

In order to determine the maximum temperatures encountered during operation of numerous electrical components in aircraft, the use of temperature-indicating paints has found wide application. Early in the war, NRL developed a series of paints which assumed at specific temperatures permanent characteristic hues. These serve as an index as to the maximum temperature obtained while in use, and the series covered the range between 125-375° C. More recently, the need has arisen for other materials ranging down to 50° C. A series of colored pigments has been prepared which adequately covers this lower range. In addition to the preparation of pigments, some improvement has been gained in vehicle formulations to carry these pigments.

Since the use of magnesium alloys in aircraft structures has been limited largely by their decided tendency to corrode, especially in sea atmospheres, considerable attention has been devoted to the preparation of inhibitive coatings applicable to magnesium. Perhaps the most significant fact that has been demonstrated during the past year was that certain salts of magnesium, principally magnesium chromate, when added to the primer as a pigment, improve its inhibitive properties. Further experimentation is underway to determine the mechanism of this action.

Increased activity in high-speed missiles and planes and the ever-increasing importance of the adhesion of coatings to such devices necessitate more fundamental study and measurement of the adhesion of films to a substrate. In the past, empirical methods have been used to measure forces indirectly related to the adhesion of organic coatings. Involving such properties as the flexibility of the film, all of these methods have been comparative and fail actually to measure adhesion quantitatively. Development of a method for direct determination of paint adhesion is of fundamental importance in the formulation of organic coatings for high-speed surfaces.

Exploratory investigation indicated that an entirely new approach using ultrasonic vibrations might provide a direct, quantitative yardstick, the amplitude and frequency of vibration required to detach the film serving as the measure of adhesive force. A method of measurement using this technique shows interesting progress. An instrument has been built which can dislodge some of the more poorly adhering films, and the force necessary to do this has been recorded (C-3286, Unclassified).

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Systematic study of limits of applicability of method and apparatus is continuing, and in process of construction is an improved machine expected to be capable of measuring directly adhesion of the high-grade paints, varnishes, and lacquers in common use.

PERSONNEL PROTECTION (C04)

Research on protection against chemical warfare agents was continued, and satisfactory progress has been made in some directions. Active liaison has been maintained with the Army Chemical Corps and with the BW program at Camp Detrick. Work is in progress on decontamination, on protective clothing, and on absorbents for gas mask cannisters, but no significant accomplishments can now be reported. Aerosol penetration of filters is under active study with emphasis on the development of more sensitive smoke meters for the detection of dispersed bacterial agents of fine particle size.

Strong emphasis is being placed on the development of the gas analyzer for submarine air. The ultimate goal is a combination instrument which will determine the principal atmospheric ingredients of interest such as oxygen, carbon dioxide, carbon monoxide, hydrogen, and hydrocarbon vapors. Especially important for the new-type submarines designed for long submergence, present efforts are being directed toward determination of the best type of analyzer for each constituent. Simultaneously, the attempt is made to adapt one analytical technique to as many constituents as possible. The job of engineering the complete instrument will be undertaken later. Most of the work on the gas analyzer will be done under outside contracts with instrument companies who are already far along the road to the solution of component parts of the project. However, research is also being continued at NRL along the lines of thermal conductivity, infrared, and the mass spectrometer.

ELECTROCHEMISTRY (C05)

Primary and secondary batteries have very important uses in submarines, aircraft, torpedoes, and in many other types of weapons. Since most of these uses require considerably more development than is occasioned by commercial application, there is continued need for research in all types of cells. Very little is known about the fundamental chemical and physio-chemical changes which occur in the active materials of lead-acid cells during manufacture of the plates.

A current investigation aims at obtaining knowledge of the factors controlling the properties of these active materials - a knowledge valuable in furthering development of the cell (C-3262, Unclassified). As an initial step in the study, the formulae have been checked or established for the compounds (basic sulfates) formed between PbO and $PbSO_4$. Phase diagrams for melts of these substances show formation of the compounds $PbSO_4 \cdot 4PbO$, $PbSO_4 \cdot 2PbO$, and $PbSO_4 \cdot PbO$. A hydrous compound tentatively assigned the formula $PbSO_4 \cdot 3PbO \cdot H_2O$ may be formed by boiling $PbSO_4$ and PbO in water suspension. Support for these compositions is furnished by X-ray methods of analysis.

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For use in identification work, X-ray diffraction patterns have been recorded for these compounds, and the decomposition products of both $PbSO_4 \cdot 2PbO$ and the hydrous compound have been determined by X-ray analysis to be a mixture of $PbSO_4 \cdot 4PbO$ and $PbSO_4 \cdot PbO$.

Investigations on submarine storage batteries have been carried out, particularly as regards new types of batteries and schnorkel operation. The effect of reduced pressure during schnorkelling on the hydrogen evolution of batteries has been investigated and conclusions drawn. The short-circuit current for the new high-capacity submarine cells also has been determined, for the purpose of planning the selection of adequate circuit breakers.

HIGH POLYMERS (C06)

Advances in high polymers have centered chiefly around three projects: (1) development by infrared spectroscopy of methods of analysis and determination of molecular structure of natural rubber mixtures; (2) the production of new plastic materials from certain organo-phosphorus compounds; and (3) the formulation of insulating varnishes for exposed electrical connectors in submarines (C-3275, Unclassified).

The infrared spectrum of a pure, naturally-occurring, rubber hydrocarbon indicates a composition of elastomers of one of two types of molecular structures (C-3285, Unclassified). Rubber from the guayule and koksaghyz (Russian dandelion) plants has the same molecular structure as that from the hevea tree and is known as "hevea-type" rubber. Chicle and balata have the same molecular structure as gutta-percha and are known as "gutta-type" rubbers. Both types have been studied over the temperature range -25° to 70° C.

In organo-phosphorus chemistry, a number of interesting possibilities have been pursued, among them the preparation of high-molecular-weight, liquid esters of phosphorus acids through condensation of dichloro- or oxydichlorophosphines with glycols (C-3180, Unclassified). Several allyl esters of phosphorous acids have been prepared and polymerized, using peroxide catalysts. Procedure for the preparation of high-molecular-weight oils by condensation of aryldichlorophosphines and aryloxydichlorophosphines with glycols has been developed to the stage where larger runs can be made and sufficient material obtained for testing as fire-resistant hydraulic fluids, lubricants, additives, and so on. Preparation of a series of such compounds is now in progress.

A voluminous and comprehensive literature survey of the chemistry of organo-phosphorus compounds has been completed and is in process of publication (C-3323, Unclassified). As complete coverage as practicable has been attained of the method of preparation and reactions of organo-phosphorus compounds, including the esters of phosphorous and phosphoric acids and various nitrogen-phosphorus compounds.

CONTROL OF FIRES (C07)

In the fire extinguishment program progress has been made toward the development of a new type of protein material for the production of improved foams capable of extinguishing either alcohol or gasoline fires. A special application is the fighting

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of fires incident to the launching of missiles of the German V-2 type in which an alcohol is used as fuel. Extensive work remains, however, on this problem.

Laboratory personnel have assisted in shipboard surveys of hazards involved in the use of hydrocarbon fluids aboard carriers. The results of this survey will be used to plot fire-protection and damage-control regulations in future design. Studies are underway on the use of low-toxicity fluoro-carbons in fire extinguishers to replace the more toxic chloro- and bromo-carbons. Much consultative work and evaluation tests have been done for the Bureaus on fire-fighting problems generally.

It was desirable to discover a permanent odorant for the toxic methyl bromide fire extinguisher in order to detect leakage from cylinders in confined spaces. The familiar mercaptans when used for this purpose were found to lose their effectiveness, due to chemical reaction with the methyl bromide. An investigation of numerous malodorous organic chemicals revealed two compounds, namely phenylacetic acid and isoamyl valerate, which retained their potency after storage tests of four months. These have been recommended for service tests.

COLLOIDS (C08)

The application of colloid chemistry to lubrication problems has occasioned an intensive study of surface activity in colloidal dispersions. Judging from viscosity and stability behavior of metallic soaps, such as those used as additives for lube oils, lubricant formulations appear to exist as colloidal dispersions rather than as true solutions of soap monomer or dimer. More detailed information concerning particle size and shape, and of the factors influencing stability of typical soap-type additives in nonaqueous systems, should aid in favorable application of such materials to Naval uses.

Simplified methods have been developed for measurement of osmotic pressures of soaps colloidally dispersed in nonaqueous solvent. Preliminary results indicate that alkali metal and alkaline earth soaps of the arylstearic acids (previously studied as rust inhibitors) disperse in benzene to give micelles in the middle and lower colloidal range whose size is a function of the previous history of the preparation.

SURFACE CHEMISTRY (C09)

Physical chemists have long regarded the frequently unorthodox behavior at the interface of two different materials as arising from the peculiarities of monomolecular layers. The physical properties of such monolayers, therefore, constitute the chief consideration in the analysis of surface activity. Principal efforts in this field have been directed toward the extension of existing knowledge of monomolecular films as they relate to lubrication, defoaming, wetting, corrosion, and similar phenomena.

Little has been known of the silicone oils concerning their surface-active properties despite widespread use of these materials in wartime application. Although one earlier project dealt with the air-silicone and water-silicone interfaces, a formal problem has just been inaugurated this year for a systematic investigation. To date, profound changes in state in the monolayer have been observed on prolonged contact of a silicone with acids and bases. Salts have a definite but smaller effect. Recent work has been directed toward determining the effect of concentration of various ions

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on the rate of change of state, the effect of the ion species, and, finally, the exact nature of the change in terms of changes in molecular configuration and/or adsorption of solute ions on the silicone molecule (C-3141, Unclassified).

A specific application of monolayer behavior rests in the control of spreading of light instrument oils, a so-called "oleophobic" monolayer resisting the flow of a liquid over a solid surface precoated with the monolayer. Extensive data has been obtained toward the correlation of chemical structure and of surface condition with the ability of polar molecules to adsorb on metals. Experimental methods have been developed for observing the effect of temperature on oleophobic films adsorbed from solution (C-3267, Unclassified).

Toward the close of the fiscal year, a fundamental study was begun of the spreading of pure organic liquids on various surfaces such as platinum, steel, brass, sapphire, and quartz with a view to determining the relationship between chemical structure and the nonspreading quality.

RADIO CHEMISTRY (C10)

Extension of the previous program, "Tracer Element Techniques," to "Radiochemistry" has provided a much broader base for nuclear studies. Although during the fiscal year experimental activities have been confined largely to spadework, extensive preparations have been underway toward more thorough and more fundamental investigations in this field. Laboratory personnel have received special training at Oak Ridge during the past year, and needed experimental facilities have been installed. Research on radioactive tracer elements is scheduled to begin soon.

PHYSICAL CHEMICAL PROPERTIES (C11)

In recent years a great deal of interest has been shown in the use of low-melting-point metallic elements and alloys as liquid heat-transfer media. For purposes of equipment design and operation, an intimate familiarity with the physical and chemical properties of these materials is required, and during the past year work toward this end has continued as rapidly as inherent difficulties would permit. Of especial interest are the elements sodium and potassium and sodium-potassium alloys of various compositions. Because of the extreme readiness with which these materials are oxidized in air, and because of the acute susceptibility of their property measurements to the presence of minute amounts of impurity, work in this field is slow and tedious.

The status of active property measurements and all measured results obtained to date are set forth in a number of NRL reports (P-3010, P-3057, C-3105, Unclassified; C-3152, Restricted; C-3201, Unclassified; C-3243, Confidential; C-3287, and C-3330, Unclassified) on the physical and chemical properties of the sodium-potassium alloys. Viscosity and density determinations are complete. Measurements still to be made include those of specific heat and of heat conductivity, together with a confirmation of earlier values obtained on wetting and surface tension.

Working on other phases of this liquid alloy project, Mine Safety Appliances Company, under Navy Contract N6-ori-146, has conducted investigations during the past two years on the mechanical and engineering aspects of the problem, with particular emphasis on heat-transfer and corrosion studies of the alloy on the equipment metals. Twelve partial reports have been submitted, and a final report is in preparation.

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ELECTRICITY

ELECTRICAL POWER SYSTEMS (E01)

Due to the ever increasing and changing requirements for electrical power in naval craft, there is a need for electrical power systems having greater capacity to supply these specialized power requirements with increased reliability. Efforts to design electrical systems which will meet these objectives are almost invariably hindered by limitations of weight and space. Aside from the development and application of new materials, increasing system capacity and effectiveness without a corresponding increase in weight and space appears to present conflicting design goals. These goals may be achieved, however, if the engineering behavior of the components and systems is better understood and expressed in convenient mathematical relationships which may be directly applied by the designer. Comprehensive studies of aircraft and submarine electrical power systems and components by the Laboratory have produced substantial contributions to such design information.

The operating voltage of propulsion systems for proposed submarines has been doubled, with a consequent increase in electrical hazards and an increased burden on protective devices in the distribution systems. The two problems are related and both are dependent upon the characteristics of the electrical equipment under short-circuit conditions. To reduce the hazard and apply circuit-protective devices intelligently, the designer must be able to calculate the current contribution of each piece of electrical equipment under various conditions of fault and must also be able to predict the tendency toward flashover of rotating machinery. This information is particularly important in the design of shipboard systems where circuit breakers, fuses, relays and other protective devices must meet minimum weight and space requirements and must be coordinated to provide a high degree of reliability and service continuity.

Available information relative to d-c short-circuit currents has been limited to theoretical analyses based on formal solution of the differential equations of current flow and the machine inductance and resistance values. As a tool in the routine design of d-c systems such information is not adequate. On the other hand, design of a-c systems has been facilitated by the use of transient and subtransient reactances and corresponding time constants of synchronous machines. These constants represent with satisfactory accuracy the performance of a-c machines during short circuits, and through their use it has been possible to calculate short-circuit current flow on a-c systems under a wide variety of conditions without the use of formal differential equations. The availability of these constants has contributed in no small measure to the high standard of performance obtained on a-c systems.

Unfortunately the engineering data for obtaining such design constants for d-c machines has not been available, since the transient properties of d-c machines have not been sufficiently investigated. In an effort to secure additional knowledge of the currents resulting from short circuits of d-c systems, a "mock" submarine electrical system at the U. S. Submarine Base, New London, Connecticut, has been under study by the Laboratory. The system is comprised of a submarine battery, propulsion

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generator and motors, power auxiliaries ranging from 1/2 hp to 90 hp, a control cubicle and power-dissipating resistors. Experimental data were obtained on the relative contribution of current by the various machines under short-circuit conditions, the effect of load and speed on short-circuit current, and the magnitude of the current and its rate of rise and decrement. Instrumentation was undertaken for the second phase of the investigation, the object of which was to obtain information relative to the internal phenomena of the rotating d-c machinery under short-circuit conditions. The ultimate purpose of this phase is to derive a group of design constants similar to those applied to a-c machines.

The introduction of higher operating voltages in submarine electrical systems has also increased the need for more accurate knowledge of the limitations of the materials used in assembling the system. Because of the severe space limitations and environmental factors imposed on the submarine electrical system, the selection of suitable insulating materials and the determination of minimum spacing between bus bars in the distribution system is critical. As one phase of NRL's complete analysis of proposed and existing submarine electrical systems, a systematic investigation of leakage currents across the surface of insulating materials was undertaken. Considerable effort was devoted to the development of suitable experimental techniques for applying typical contaminating material to the insulation and for detecting and evaluating breakdown of the insulation under dielectric stress. Curves were obtained of breakdown voltage as a function of bus bar spacing and surface contamination for a variety of insulating materials.

Some time ago the Laboratory undertook a problem dealing with the determination of the best electrical system for use in carrier-based aircraft. It soon became apparent that the investigation required to arrive at recommendations for such a system would need to be extremely broad in scope and fundamental in character. It was further evident that the primary value of such an investigation would be the development of a method for arriving at the optimum design of an electrical system for any given aircraft rather than the specification of a particular system for carrier-based planes or other general class of planes.

The Laboratory's approach to the problem has been to divide the aircraft electrical system into a number of classes of components such as generators, motors, switch gear, protective devices, actuators, cable, etc., and to subject each class of components to a detailed investigation. Since weight is a factor that is more readily analyzed than other system characteristics, e.g. reliability or maintenance, the general objective of each of the component studies has been to determine the system voltage and frequency for which the component may be designed with a minimum of weight and to attempt to develop mathematical expressions indicative of the manner in which the component's weight will vary with changes in each of the design limitations imposed upon it by the system.

As a result of the analysis of d-c generators made during the last fiscal year, relations between generator weight and power output, rated voltage, and speed have been obtained. Since manufacturing experience has been limited with few exceptions to 24-volt d-c and 120-volt a-c aircraft generators and motors, it has been necessary to design several machines of various power outputs, frequencies, and voltages for the experimental phases of this work.

In conjunction with the investigation of the weight-voltage relationship of aircraft cable, (E-3145, Restricted), it has been necessary to study the heat transmission properties of cable in order to evaluate more accurately the effect of temperature

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limitation on cable weight. An expression for the power which may be transmitted over a cable subject to a temperature limitation as a function of cable dimensions, insulation thermal conductivity and convection coefficient, is being formulated.

Component weight studies on d-c motors, a-c motors and transformers have been undertaken.

ELECTRICAL POWER EQUIPMENT (E03)

The comprehensive studies of shipboard and airborne electrical power systems pursued by NRL have been supplemented by numerous detailed investigations of the individual system components. While the general objective of all of these investigations has been to achieve a better understanding of the limitations to improvement of the performance of electrical power equipment, the origins and immediate objectives of the individual problems are quite varied. While some component investigations are a direct outgrowth of the system studies in progress (E-3169, Unclassified) others are undertaken to correct specific faults observed in performance of certain components under service conditions (E-3160 and E-3228, both Restricted). A third group of studies deals with the modification of equipment or the development of new equipment to meet the changing requirements of the fleet.

An example of the latter type of problem is the development of a suitable electrical power supply for guided missiles, pilotless aircraft, and rockets. Batteries are now commonly used as a source of electrical power in such installations but additional power conversion stages consisting of one or more motor-alternator sets are usually required and the result is a system with excessive space and weight requirements.

The Laboratory has undertaken the development of a packaged electrical power supply which will furnish the desired power at a fraction of the space and weight requirements of present systems and with greater reliability. An alternator of the permanent-magnet-field type for operation at high altitudes has been designed to eliminate sliding contacts and their associated problems. The alternator will be driven by a gas turbine. It is expected that the packaged unit, which will include the alternator, turbine, fuel and necessary control equipment, will weigh not more than 50 pounds and will have an output of 1-1/2 kva for a period of 15 minutes.

Changing requirements upon shipboard electrical power systems have also created a need for new and better electrical equipment. For example, because of excessive amounts of moisture and acid in the atmosphere of a submarine, the electrical system tends to develop grounds which may disable the propulsion system of the craft. The higher operating voltages proposed for submarines now under construction, make it increasingly important that such insulation failures be anticipated and avoided if reliable performance is to be maintained. This can be accomplished by measuring the system's insulation resistance to ground, since changes in the insulation resistance reflect changes in the insulating characteristics of the system.

The conventional method of ground detection consists of taking voltage measurements from each line of the energized system to ground and across the two lines. These readings are then applied to a formula which yields a measure of the system's insulation resistance. Such measurements are not reliable because of variation in system voltage while readings are being obtained and because of excessive metering errors on high resistance grounds. Another disadvantage is that the system must be energized to obtain the measurements.

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The Laboratory has therefore developed a ground-detecting device which utilizes a standard megger in a simple bridge circuit. By its use, direct resistance measurements can be made with improved accuracy on both energized and de-energized circuits, a-c circuits, and variable voltage circuits, -- particularly at high values of resistance. The use of this device is expected to reduce materially the number of submarine power system failures.

Designing electrical power equipment with minimum space and weight requirements, suitable for use in aircraft electrical systems is particularly difficult because of the wide variations in ambient temperature, pressure and humidity, and the severe conditions of shock and vibration encountered. Many conventional electrical components prove entirely unreliable or, at best, render only marginal service when adapted for use in aircraft.

Such is the case with the reverse-current cutouts now used in aircraft to connect the generator to the main distribution line when conditions are such that the generator can supply power to the line. These cutouts disconnect the generator when the line begins to supply power to the generator -- that is, when a reversal of current flow occurs which might damage the generator. The conventional magnetic-type cutout has never given completely satisfactory performance under the wide range of conditions associated with aircraft service. Preliminary investigations by the Laboratory indicated that effort should be concentrated on the development of a cutout based on some new principle if really significant improvement in size, weight, or performance was to be obtained.

Several devices making use of the differential voltage between the generator and battery as the controlling factor have been investigated and a new type of cutout circuit utilizing a permanent-magnet control element to trigger a unique thyratron circuit has been devised. Tests made upon an experimental model indicate that a cutout using this new control element is capable of repeated operation at the same differential voltage for generator voltages varying from 20 to 30 volts. It can be designed to be practically independent of changing conditions of altitude, humidity, and temperature over a range of -50° C $^{\circ}$ to $+70^{\circ}$ C. The same cutout can be used on any 28-volt d-c system regardless of generator output rating and, with slight modification, the principle can be applied to higher-voltage, d-c systems (E-3237, Unclassified).

Time-delay relays have numerous applications in aircraft, but difficulty has been experienced in obtaining uniform operation under the extreme conditions of temperature and atmospheric pressure encountered. Various principles involved in obtaining time delays have been investigated by the Laboratory and two units suitable for use in aircraft have been developed (E-3292, Unclassified). One utilizes electrically heated, bimetallic strips to accomplish the time delay and offers the advantages of simplicity of design, light weight, and small size, but it has a recycling time of approximately 6 seconds. The second unit, using a constant-speed, d-c motor, is somewhat heavier and larger but provides instantaneous recycling. Both relays are continually adjustable for time delays between 5 and 30 seconds.

Increased requirements for electrical power in military aircraft have led to multi-generator, high-capacity d-c electrical power systems. A short circuit occurring in these high-capacity systems may result in severe damage to the aircraft itself, in addition to disabling its electrical system. The Laboratory has devoted considerable effort to the development of a protective system for aircraft generator power supply

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systems which will provide protection from any fault occurring in the generator or between the generator and the main distribution line. The problem is a complex one, since such a system must be capable of detecting both excessive current and overvoltage in the generator circuit. Provision must also be made for automatically selecting the faulty generator and isolating it from the rest of the multigenerator system.

To date, the Laboratory's investigation has dealt primarily with the problem of ground-fault protection. The optimum response time and sensitivity required for adequate ground-fault detection have been determined and a suitable detector has been developed which operates on the differential principle, comparing the current at different points in the generator circuit. It is capable of sensing faults of as little as 10 percent of the rated generator capacity. Methods of overvoltage protection are currently being investigated and a system developed by the Laboratory has produced promising results.

A major contributing factor to many of the problems encountered in aircraft electrical systems is variation in system voltage resulting from instability of the voltage regulators which are currently available for aircraft use. Before marked improvement in regulation can be achieved, it is necessary to acquire a better understanding of the many factors which affect voltage regulation. A detailed theoretical and experimental study of the subject is being conducted by the Laboratory (E-3206, Unclassified).

The general approach to the problem has involved mathematical analysis of generator performance and the development of methods of utilizing these mathematical expressions of generator characteristics in the study of the generator-regulator-load system. One of the first obstacles encountered during this investigation was the lack of a practical means for expressing mathematically the electromagnetic characteristics of a d-c generator. A simple, yet accurate, method of steady-state analysis of aircraft d-c generators has been developed by the Laboratory and used to good advantage in the investigation of factors affecting voltage regulation. The method of analysis is also applicable to load and speed control problems.

Early efforts to utilize these mathematical expressions of the generator characteristics in the study of the generator-regulator-load system were directed toward the derivation of differential equations for the equivalent electrical circuit and led to simultaneous solution of several unwieldy differential equations. The similarity between regulators and servomechanisms led to the abandonment of the cumbersome differential equations in favor of an attempt to apply established servomechanism theory to the generator-regulator system. This has been done with unusual success and it is now possible to predict reliably the operation of a given regulator-generator combination. Considerable effort has also been devoted to the development of suitable experimental methods for testing a regulator independent of any generator. Such a method is needed to verify the mathematical expressions which have been derived for the performance of the regulator and to provide a means for measuring directly changes in performance resulting from a known modification of the regulator.

As previously mentioned, some component studies are a direct outgrowth from, or very closely related to, the overall system studies being conducted by the Laboratory. Such is the case with the investigations being directed toward standardization of aircraft electric motors. Electric motors of various sizes are used in ever increasing numbers for a variety of applications in modern military aircraft. Representative

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types of motors in current use have been studied by the Laboratory in an effort to formulate some design standards on nominal weights, efficiencies and dimensions for motors of a given rating. The investigation is complicated by the necessity for considering the effects of altitude and ambient temperature on motor rating, and the fact that many aircraft motors are not intended for continuous operation so must be rated for intermittent operation at various duty cycles.

Since the expected life of electric motors depends to a great extent upon the rate of insulation deterioration at the operating temperature of the motor, it has been necessary to obtain experimental information concerning the temperature-life characteristics of insulating materials used in the motors under consideration. Although such engineering data existed for insulation life of one year or more, no information was available for 1000 hours or less (1000 hours being the acceptable life of an aircraft electric motor).

The information has been obtained by aging the insulation of a number of coils subjected to thermal, electrical and mechanical stresses simulating conditions existing in armature windings during operation. It is interesting to note that the results obtained for Class A insulation were in agreement with an extrapolation of available information for insulation life in excess of 1000 hours. This agreement extended from 1000 to 40 hours below which point the resulting life was greater than anticipated from the extrapolation. This has been explained as a result of thermoplastic flow of the oil constituents of the insulation at the temperatures involved which prevented embrittlement and flaking of the insulation, the major cause of insulation failure.

Similar experiments conducted on Class B insulation, which is composed of glass fiber with organic binders and is supposedly more resistive to higher temperatures, yielded a life-temperature characteristic inferior to the corresponding characteristics of Class A materials. These unexpected results are not conclusive, however, since a dielectric stress considerably in excess of the 25 volts maximum normally encountered in these aircraft motors was used during the life-temperature tests, and subsequent investigations of the effect of dielectric stress on insulation life have revealed that the life of Class B insulation is much more severely affected by increased dielectric stress than is that of Class A insulation. A new series of tests is now being conducted to determine the life-temperature characteristics of Class A and B insulation at 25 volts dielectric stress. Methods of measuring armature temperatures while the motors are operated in an altitude chamber are also being investigated so that additional experiments can be conducted under various conditions of altitude and humidity.

OPERATIONAL EQUIPMENTS (E04)

Modern naval operations require the closely coordinated activity of a great variety of naval craft. To achieve the precision performance required for such coordinated operation, there is an ever increasing demand for special devices capable of accurately and reliably sensing, transmitting and indicating information required for efficient operation of the craft (E-3295, Restricted). Insofar as possible, these devices must operate automatically to eliminate the inaccuracy associated with manual control and to avoid the assignment of additional tasks to already overburdened personnel. Electrical and electromechanical devices have been found to be particularly suitable for such applications.

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Operational equipment studies conducted by the Laboratory have included a considerable amount of work on underwater log systems used to measure the speed of ships and the distance they travel through the water. An improved method of calibrating the pitot-tube type of log has been developed and should result in more accurate operation of the log and eliminate the necessity of repeating measured mile runs of the ship for purposes of recalibrating the log, so long as the same type of rodmeter is used and its position on the ship's hull is unchanged. The feasibility of developing a new type of log which would measure fluid flow by electromagnetic methods has also been under investigation at the Laboratory.

The accuracy of many types of electrical operational equipment is in large measure dependent upon the accuracy with which the frequency of the power used to actuate these devices is controlled. Log systems, and shaft revolution indicators, for example, require a constant frequency power source as a time reference.

Automatic frequency controls are used to regulate the speed of motor-generators or dynamotors that supply the alternating current for these devices. The electromechanical types of frequency control currently in use have many deficiencies, however, since they utilize complicated arrays of tuning forks, synchronous motors, differential gears, rheostats and electronic tube amplifiers. In addition to being bulky and sluggish in response, many components of the system are fragile and subject to failure under the severe conditions of shock and vibration encountered in naval service.

A simplified type of frequency control unit using magnetic amplifier principles has been developed by the Laboratory. This unit has no moving parts and is, therefore, extremely rugged. An experimental model has controlled the frequency of an 80-volt amp dynamotor's output within ± .1 percent at 60 cps under conditions of fluctuating supply voltage and dynamotor load. The speed of response of the new system is approximately five times faster than that of the electromechanical system. It is believed that the magnetic-amplifier-type control will be about one-fourth as large and heavy as the electromechanical type. A prototype model is now under construction and will be subjected to a variety of tests to establish further its suitability for shipboard use. The magnetic amplifier principles used in this unit have many other applications in the field of operational equipment which will be investigated by the Laboratory.

The Laboratory has recently started an investigation of tank-level-indicating systems. Systems currently in use are unsatisfactory because of maintenance problems, inaccuracies, and unreliable operation. The efforts of the Laboratory are directed toward the development of a simple, dependable system which will have a high degree of accuracy under conditions of pitch and roll, and will provide for numerous remote indicators.

There are two phases to the problem, the first of which deals with the measurement of the fuel level in a tank containing two liquids simultaneously -- such as gasoline and sea water. Many different measuring schemes have been investigated and, to date, a simple capacitance bridge type circuit appears to be most promising. A capacitance unit consisting of a metal tube with a thin coating of insulating material is installed in the tank. The metal tube serves as one plate of a condenser, and the sea water as the other plate. Variations in the level of sea water in the tank then produce a measurable change in the capacitance of the unit. Considerable difficulty

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has been encountered, however, in finding a suitable insulating coating which will adhere to the metal tube and withstand the chemical attack of both gasoline and salt water.

The second phase of the investigation deals with the measurement of the liquid level in a tank containing only one liquid, such as fuel oil. Preliminary studies indicate that the determination of the liquid level by pressure measurements may offer a suitable solution. Investigation of various pressure-sensitive electrical pickups is underway.

The need for new and improved operational equipment is by no means limited to shipboard applications. The complexity of modern military aircraft and the ever increasing speeds at which they operate have created numerous problems in the field.

For example, conventional instrumentation used to indicate the performance of reciprocating aircraft engines is not applicable to the turbo-jet type of aircraft power plant. To determine the net thrust developed by a jet engine during flight tests, it has been necessary to obtain a photographic record during the flight of certain pressure-sensing instruments and subsequently perform a series of laborious calculations to compute the thrust. Such a procedure obviously cannot provide the pilot with any indication of the operating characteristics of the jet engine while in flight.

The Laboratory has conducted an investigation which makes feasible the development of a device to provide a continuous direct indication of the thrust produced by a jet engine. Special pressure-sensing devices are used to convert inlet and tailpipe pressures into electrical signals which are fed into an electrical analog computer designed to solve the thermodynamic equations involved. The output of the computer can be used to operate either a panel indicator, which provides a direct reading of thrust produced, or a flight recorder. A prototype model of the computer, weighing only 6.6 pounds, has provided an over-all accuracy of better than ± 1 percent during laboratory tests.

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MECHANICS

SHOCK AND VIBRATION (F03)

Shock and vibration test work for the Bureaus, as in past years, consisted in part of tests of equipment and in part of measurement of characteristics of the available shock and vibration machines (S-3186, Unclassified). Two new machines, a 500-lb vibration machine and a medium-weight shock machine (F-3328, Unclassified) were installed during the fiscal year 1948.

Research under this program included field shock trials during the spring and summer of 1948. In cooperation with the David Taylor Model Basin and the Underwater Explosion Research Group at Norfolk, a series of full-scale shock tests of the USS NIAGARA (APA-87) were conducted in Chesapeake Bay. A series of 23 charges were fired with increasing shock intensity. The final explosion caused hull failure due to whipping. NRL was concerned with:(1) the effect of shock on electronic equipment and the effectiveness of the shock mounts for such equipment; and (2) the forces transmitted to a foundation by a nonrigid mass during shock. For the latter, the forces created by a boiler on its foundation were studied, and extensive instrumentation and proper mountings incidental to the measurement of transient motion were devised and installed. In spite of some adverse weather conditions valuable data were obtained which are being processed to provide information needed by the Navy for improvement of the shock resistance of shipboard equipment.

One problem, of considerable immediate interest to the Navy, studied under this program dealt with periscope vibrations. It had long been known that excessive vibrations are present in the attack periscope at submerged speeds over six knots, and methods had therefore been developed for accurately measuring in the field the frequencies and amplitudes of periscope vibration while the submarine was proceeding at periscope depth (S-3195, Restricted). At the request of the Bureau of Ships, NRL undertook a study of periscope vibrations at high submerged speed. It was found that the largest amplitude vibration was associated with formation of vortices in the water flow passing the periscope (F-3332, Confidential).

Development of improved velocity-type meters was undertaken and shock motions were analyzed by means of reed gages (F-3302, Unclassified). In connection with these latter studies it was found that the "shock spectrum" derived from the reedgage record provides design conditions for "shockproof" equipment in the form of equivalent static accelerations of the shock motion, and a rational method for comparing the severity of different shock motions. The investigations indicated that the effect of a given shock motion is not the same for all structures and that the load for which a structure should be designed depends not only upon the shock motion to which it is to be subjected, but also upon its natural frequencies.

Work under the Shock and Vibration Program was substantially aided by the six Shock and Vibration Symposia held during fiscal 1948 for the purpose of a free discussion of various problems. These discussions are recorded in NRL Reports Nos. S-3151, S-3181, S-3200, S-3229, S-3290, all Confidential, and S-3276, Unclassified.

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STRENGTH OF SOLIDS (F04)

The Shock and Vibration studies discussed above are assisted by Laboratory investigations of shock strength of shipboard materials. A novel shock-machine test was devised which subjects cylindrical samples to a damped vibration motion. Such motions are typical of many mechanical-shock events expected in service. When the amplitude is high enough to cause some plastic straining and the test is repeated to fracture of the test sample the result is a very pertinent kind of a low-total-cycle fatigue test. Modifications of this test and adaptations of standard fatigue machines to low-total-cycle testing have been explored. It is already clear that comparative mechanical strengths under shock loads will differ significantly depending upon the severity of the shock at which the comparison is made (F-3381, Unclassified). This work is assisted by a research contract at the University of North Carolina.

Studies of the causes of brittle fracture and of the dynamics of fracturing were also assisted by a research contract at the University of North Carolina. This problem is an attempt to establish the basic principles of mechanics which govern growth and propagation of fracturing cracks in solids. The contract studies centered about slow-speed bend tests of notched bars under conditions which permit measurement of the work per unit area required to extend the fracturing crack. At NRL a useful model of fracturing was made by arranging a dead-weight load on a centrally notched metal foil in tension so that extension of the crack occurred over a suitable time interval. Careful study of this model and of the University of North Carolina results showed that a very significant phenomenon precedes onset of brittle fracturing in ductile metals. This phenomenon is the development of relatively very small work per unit area requirements for extension of the fracturing crack. It was shown that onset of cleavage fracture was not necessary for the development of rapid fracturing on released strain energy in steel. Considerable effort was devoted to the possible influences of cleavage fracture, strain rate, size effect, and discontinuous yielding upon the development of brittle fracturing. One of the most helpful techniques employed in the studies of fracturing at NRL has been the extensive use of high-speed motion-picture photography.

During fiscal 1948 exploratory work with armor materials was continued. Plastic-fiber armor received the most attention. Investigations of strength distribution statistics for nylon-armor-cloth threads as a function of length were conducted. The results suggest that the rupturing instability includes a localized twisting of the thread at the position of rupture. A 3000-frame-per-second movie was made of a nylon thread rupture. The break was confined to a very short section of thread and was completed in less than the time between frames.

Several more closely applied armor-materials investigations were in progress. A good lead toward a useful new armor material was obtained with the NRL discovery that pads of loose type-300 nylon fibers provide approximately the same resistance to fragment penetrations as do equal-weight pads of nylon armor cloth. The possibility that better aluminum alloy armor may be obtained by forging than by rolling has been under consideration for some years. The extensive trials necessary to determine how much improvement, if any, can be obtained by forging were started during fiscal 1948 with the cooperation of aluminum-plate manufacturers and of the Naval Gun Factory.

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The Strength of Solids program has received notable assistance from discussions presented at a weekly Strength of Solids Seminar--established for mutual assistance of the workers in reviewing advanced literature related to this topic.

PENETRATION BALLISTICS (F05)

Studies in this program are grouped under three problems: penetration dynamics, incandescence related to impact flash and high velocity, and techniques for the study of gunfire damage to aircraft structures and materials. A closeworking, mutually profitable liasion was established with the Johns Hopkins Applied Physics Laboratory in connection with studies of fragment penetration. The work accomplished included a theoretical review of aircraft vulnerability as affected by possible missile shatter at impact and extension of aluminum-plate penetration curves for high-velocity fragment-simulator impacts.

Results were obtained for incendiary effect of impact flash due to Cal .50 bullet impact with a variety of thin sheet materials. At the end of fiscal 1948 sufficient information was at hand to conclude the development of a useful testing technique. During the spring considerable attention was given to study of pressure-type damage associated with very-high-velocity impacts against aluminum aircraft structures. A number of 3000-frame-per-second movies were made which show the major features of interest very clearly. The brilliant high-velocity-impact flash develops gradually with increases in impact velocity. The violence of the event is quite sensitive to multiple strikes at the entrance impact and is increased by the confinement of the volume containing the flash.

AERODYNAMIC BALLISTICS (F06)

Work under this program was moved during the first months of fiscal 1948 to improved space provided by the addition to NRL's Building 11. At this time a change was made from Cal .30 to Cal .50 for the scale of the work and designs were begun on a 37-mm air-drag experiment. A study was initiated of the end effects for the baffled tubes used as momentum traps in the air-drag work. The information obtained extended the sphere air-drag values reported in NRL Report No. 0-2851 (Restricted) to 1/2-inch spheres and to high Mach numbers and, in general, provided increased confidence in the value of the experiment. Results remained tentative at the end of the reporting period pending completion of additional end-effect and baffle-hole-size studies.

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METALLURGY

PHYSICAL METALLURGY (M01)

Physical metallurgy includes those activities that are concerned with the study or improvement of the physical properties of metals such as strength, ductility, electrical conductivity, or magnetic permeability. It ranges from the practical to the theoretical, and the problems investigated at NRL likewise cover a wide scope.

Strength of metals is obviously important, and it is natural that much attention has been given to many of the aspects of this property. For example there is a need for lightweight alloys that are stronger than those now available for use in rockets and jet-propelled aircraft. Research on many aluminum alloys has been carried out (M-3183, Unclassified), and an alloy of aluminum and mischmetal (an alloy primarily of cerium and lanthanum) has been shown to have superior strength in the cast condition over other aluminum alloys up to temperatures of 400° C.

Strong aluminum alloys at room temperature are well known, but there was little information available on the influence of very fast cooling rates on age-hardening alloys. The widespread practice with aluminum alloys of rapid cooling at uncontrolled velocities made necessary better knowledge of the relationship between strength and speed of quenching. To meet this need a modified end-quenched test bar (similar to the Jominy test bar familiar in ferrous metallurgy) has been developed and used to study the effect of rapid cooling rates upon the hardness of typical aluminum alloys either before or after age-hardening.

Several aspects of the problem of the strength of steel have also been under investigation. In one, the anomalous loss of toughness of some hardened steels after a tempering treatment intended to increase toughness and ductility, has been examined. This loss of toughness, at tempering temperatures, has been attributed to the formation of austenite during the tempering cycle, and its decomposition on cooling. The mechanism of the reactions are being intensively investigated.

Another attack on the problem of the strength of steel was the investigation of the transition temperature as revealed by the notched-bar impact test. Below the transition temperature the fracture is brittle, and absorbs little energy, possibly as little as 5 foot-pounds. Above the transition temperature the fracture is ductile and may absorb as much as 100 foot-pounds of energy. In view of the fact that the transition temperature lies in the region of -200° F to +360° F for different steels, it is desirable to use steels above their transition temperatures if they are likely to be subject to impact-type loads in service. Conversely, it becomes desirable to lower the transition temperature of commercial steels if possible. In the past year investigation has been made with experimental heats of a single basic steel, with a systematic variation in the amounts of added elements, and transition temperatures determined. To date, transition curves have been obtained for copper, manganese, molybdenum, nickel, and silicon, and of these only nickel has been found to depress the transition temperature.

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Still another problem in the strength of steel is armor plate. Work has been carried out in this Laboratory on the strength of the bond between the layers of a laminate plate under impact and ballistic loading. For the bond, aluminum, copper, and nickel foils and steel screen have been used. While the tests are not yet complete, it is definite that composite sheets can be made to delaminate when struck by a projectile, but it is not yet known how this affects resistance to penetration by the projectile.

Another problem involving strength is that of stronger cast steels to be used in anchors in order to decrease the deadweight of the anchor and its auxiliary equipment. The steel must have a high yield point, but must not require involved foundry practices or heat treatments to develop its properties. Such a steel has now been produced and tested on a laboratory scale, and requires only test in an actual anchor. The answer was found in a manganese-molybdenum steel with the addition of boron.

Physical metallurgy studies are also employed at the Naval Research Laboratory in fields of other fundamental sciences. One is the production of metallic flakes for use in absorbers for radar frequency radiations. These flakes are subsequently compounded in a plastic; and form the basis for absorbing energy from a radar beam. The metallurgical problem involved 1) producing fine flakes from small particles, and 2) determining which properties of the flakes were affecting the absorption. This problem requires the correlation of properties of metal particles (a few microns by a fraction of a micron) with properties such as complex magnetic permeability and complex dielectric strength. To date flakes from impure carbonyl iron powder have been the outstanding performers, but no clear-cut answer to the cause of the behavior has been found, except that the results appear to indicate that the answer lies in part in the small particle size of the carbonyl iron.

Still another aspect of research in physical metallurgy is the study of the properties of metals not yet in commercial use. In this field a laboratory has been equipped for the production of metallic titanium and its alloys. The laboratory is equipped for vacuum melting and vacuum annealing, for sintering metallic powders in vacuo, for the preparation of pure titanium, and for production of the special refractories that are needed with titanium. A high-temperature, high-vacuum melting furnace has been built, in which temperatures of 2500° C and vacua of 10^{-6} mm Hg are attainable in workable periods of time. A hot-filament type of cell for the preparation of pure titanium has been completed. In this cell, under vacuum, pure titanium is transferred to a heated titanium filament from a container of commercial titanium by means of the titanium-iodine reaction. The cell is capable of producing oxygen-free titanium in useable quantities, having a 48-inch titanium filament.

MELTING AND CASTING (M02)

The widespread use of castings in the Navy is the result of the ease of production of many items by this method combined with the ability to use alloys that cannot be fabricated by other methods. However, the practice of metal casting is far from perfect, and the fundamentals are not all well understood. For that reason NRL emphasizes research directed toward the melting and casting of metals. As its field of study it has taken melting methods, fluid metal flow, solidification, characteristics, evaluation of castings, and improvement of molds.

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A melting method under investigation recently has been concerned with the improvement of naval bronze. This alloy absorbs gases from the furnace atmosphere, particularly oxygen and hydrogen. One method that has been used to remove gases from melts has been the introduction of an inert gas near the bottom of the melting crucible and permitting it to bubble to the surface. The bubbles, being initially pure gases of the type introduced, have low partial pressures of the gases in solution in the melt, and thus tend to "absorb" gases dissolved in the melt to purify the latter. Experiments have been carried out on the use of dried nitrogen bubbled through a naval bronze, contaminated with hydrogen, and it has been found that the resulting metal shows a definite improvement in mechanical properties.

In the field of fluid flow, colored motion pictures were completed of the flow of molten steel in several types of gating systems, that is, in several different arrangements of paths leading to the mold. The pictures show flow when the metal is poured down a vertical tube or down gate and then introduced into the mold by different devices, such as the finger gates (several inlets in the horizontal plane), horn gates (inlets below the mold), and step gates (several inlets in the vertical plane). The film is descriptive, but several of the findings are at variance with some widely held views, and has aroused much interest wherever shown. It is expected that it and its sequels will considerably improve gating techniques (M-3355, Unclassified).

As part of its activities in the freezing of metals, NRL investigated the use of gas-producing exothermic compounds in blind risers for steel (M-3148, Unclassified). By blind riser is meant a cavity attached to the mold cavity proper, and entirely contained in the molding sand. Its function is to supply molten metal to the casting proper as the latter solidifies and shrinks, and thus prevent the formation of shrinkage cavities. In order to function at all, such a riser must remain molten longer than the casting proper and be able to feed its molten metal into the mold as the latter shrinks. To achieve these ends, the riser must exceed some minimum size; but the metal remaining in the riser after complete freezing is all scrap and a loss in the melting operation. Therefore, it is desirable to keep a riser as small as possible. This can be done by any means that will keep the temperature of a riser high or that will supply a pressure to force the viscous metal out of the riser. One investigator believed that he had improved riser efficiency, that is, decreased riser size, by introducing into the riser a material that would react on contact with the molten metal to evolve gases at a high pressure. This interesting claim has been investigated for steel in sand molds. The results show that it was not the evolved gases that produced the improved feeding; it was the higher temperature produced in the riser by the exothermic reaction of the compound. This effect of exothermic materials in risers to raise the temperature is well known. By using pressures not resulting from chemical reactions, that is, from a cylinder of compressed gas, it was established that pressure alone does not force liquid metal into voids in sand castings, and that increased pressures actually tend to push out the walls of the mold and injure the casting. Excessive pressures will destroy the mold.

A useable casting, made to a specification is often very difficult to produce. Inspections of the casting to insure that it does meet specifications and needs are often even more difficult to make. Several investigations of inspection methods have been made. One was the attempt to uncover the errors that creep into the transverse test bars that are cast at the same time as the casting proper, and are expected by producer and user to show the properties of the casting. At any rate they are used to accept or reject castings. It was found that some of the methods commonly in use in casting such test or arbitration bars may lead (1) to elliptical instead of round cross-

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sections and to surface defects, and (2) to variable tensile properties along the length of the specimen. Transverse strength and tensile strength were found to be so poorly correlated that one cannot be used to calculate the other (M-3304, Unclassified). To overcome these difficulties, it was found desirable to use a hard chromium-plated steel pattern for the test bar, to use only fine grained sand in the test bar mold, to ram the mold horizontally, and to pour the test bar horizontally but to upend it to a vertical position immediately after pouring.

Another defect in castings apt to be missed on inspection is strained parts. These strains arise from unequal cooling in the mold when different parts of the casting have different volume-to-surface ratios. Sometimes these strains become actual cracks, when the stresses exceed the strength of the weaker member. At other times the internal stress does not produce fracture until an external stress is also applied, and the combined load becomes too great. Other times warpage, not fracture, results. In any case it is desirable to remove these below-critical stresses. The Laboratory has one of the few so-called "relaxation" machines, which is capable of measuring the changes in externally applied stresses to produce a constant strain over a wide range of temperatures. By use of it, results were secured that showed that stress relief in gray iron is very slow below 1000° F, but increases rapidly as the temperature is raised (M-3296, Unclassified). In a sense these were only laboratory results of uncertain validity in foundry practice and therefore, more conventional tests were made in parallel. Wheels with heavy rims and light spokes were cast which have large locked-in strains. By cutting the rim, and measuring the dimensional changes, a test of the elastic stresses is secured. Wheels were heat-treated over a series of temperatures before cutting, and stresses determined afterwards. As was to be expected, the results agreed with those from the "relaxation" machine. Furthermore they showed no stress relief resulting either from long-time room-temperature ageing or from heat treatment at 600° F, as some members of the foundry industry had reported.

In the field of gun metal castings, porosity is an important source of failure, yet its detection in castings is difficult. It is standard to apply a fluid under pressure to search for porosity, but this test is of limited utility, and subject to the conditions of test, such as fluid and pressure and length of test. A test such as radiography is much to be preferred, but it is difficult to relate imperfections as seen in a radiograph with harmful porosity. Simultaneous tests have now been made on cast plates of gun metal in a search for a correlation (M-3254, Unclassified). The plates were investigated as cast, and at several thicknesses as the surfaces were machined off. It was found that castings which showed a slight amount of shrinkage in the radiograph were of questionable acceptability, that castings showing somewhat greater shrinkage were more likely to leak; and that castings with much shrinkage and tears (internal cracks) were poor risks. It would appear that radiographs as well as pressure tests should be made when castings for critical use are to be inspected.

WELDING (M03)

The importance to the Navy of efficient welding is without question. One of the more important problems that has arisen from the widespread use of welding is that of weldability, the problem of whether two materials can be joined in a structure by welding without risk of cracking under the various conditions of use. This aspect of welding naturally is comprised of two parts--one, the welding of materials without cracking at the time of welding, and two, the welding of materials that will not develop

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failures later under the most extreme conditions encountered in service. The investigations of welding at NRL fall into these two categories.

The most obvious and always-present problem with welding is the prevention of immediate cracking. Frequently it is necessary in the fabrication of military equipment to weld studs to plates, for example, to Class B armor. Such studs obviously must not pull off, but unfortunately frequently have done so. The prevention of such failure has been under investigation for some time, but now has been found to have been satisfactorily solved by the commercial development of serrated ferrules. When the plate is free of dirt and scale, and has been locally preheated, studs of type 309 (25 percent Cr 12 percent Ni stainless steel) and of mild steel welded to plate with the serrated ferrules develop welds that are crack-free and as strong as the stud.

A procedure was developed for welding high-temperature steam pipes of cast 1/2 percent Cr 1/2 percent Mo steel. Good ductility in the welded joints was obtained when the metal was first preheated to 300-500° F, welded, and subsequently stress-relieved at 1200-1350° F.

As an attempt to describe cracking in the weld area, or underbead cracking, more quantitatively, a new method of measuring cracking in the base metal was developed. The weld area was sectioned, etched lightly, and examined microscopically. More consistent measurements of average crack lengths were obtained than were secured by using magnaflux.

The second aspect of weld failure, cracking at a later period resulting from inability of the weld to withstand service stresses, has largely assumed the character of a search for test methods that will predict performance of a weld. NRL participated in a widespread program under the auspices of the Welding Research Council to correlate small-scale tests with the performance of large structural members. This was done by performing small-scale tests on large beams that had been tested to failure at Columbia University. While much effort has been devoted in the past to the development of specimens for use in the impact test, such as the notched Charpy bar, this method has limitations, and attention is being turned to the metallurgical characteristics of the weld, such as microstructure and porosity and to temperature attained in welding, strain-rate, and restraint in the weldment.

ANALYTICAL METHODS (M04)

In its program to develop and improve analytical methods of dealing with metals, projects were carried out in radiography and in gas analysis.

The initial work with microradiography has been continued. This is the method whereby X-rays are used to study the microstructures of metals directly. The small-scale structure revealed by X-rays is photographed in fine-grained film and then enlarged. The method is a useful addition to metallography because it reveals the three-dimensional metallic structure in place of the two-dimensional intersection seen in the usual photomicrograph. The method, however, has its limitations in its relatively low order of magnification, about 100X - 200X. Its performance with many different types of metallic structures and metals has been examined.

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Fluoroscopic examination of metals would offer a rapid commercial method of examining light metal castings if it could be made sufficiently sensitive. In the past year, special German equipment using a Seifert focusing X-ray tube has been put into order, and equipment for investigation of the fluoroscopy of rotating specimens has been assembled.

Vacuum-fusion apparatus for the quantitative determination of gases in metals, particularly of oxygen in titanium has been built. Initial trials suggest that this will be one of the most sensitive instruments yet built for the analysis of gases in metals by means of vacuum fusion.

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OPTICS

OPTICS OF THE ATMOSPHERE AND OF THE SEA (NO3)

The atmosphere just above a water surface, as a transmission medium for various optical spectral regions, is of naval interest in connection with communications and signalling. Equipment was constructed and put into operation to measure the transmission of the atmosphere at night over a 9-mile path between the Chesapeake Bay Annex and Tilghman's Island, Md. A near-infrared transmissometer, submitted by the Bureau of Ships, was tested over this range and the results compared with the transmission for visible light. The near-infrared transmission was found slightly greater than the visible transmission under most conditions. Preparation of equipment to measure the transmission of ultraviolet light was also undertaken, but was not completed by the close of the year.

Research under the program also included a continuation of the study of sky brightness. One phase was concerned with the brightness and polarization of the daylight sky. Observations at several localities and at several altitudes above sea level for several altitudes of the sun taken from four series of measurements carried out at Washington, at Davos, Switzerland, at Bocaiuva, Brazil, and in Maryland were assembled and compared (NRL Report N-3257, Unclassified).

Measurements having been taken from the surface to an altitude of 10,000 feet, research on sky brightness and polarization continued from 10,000 to 40,000 feet with B-29 aircraft operating under Project Apollo from NOTS, Inyokern, California. The measurements were assembled and compared with theory and the need for further work determined. The results of the work were of general interest in upper air research and of importance in the development of guided missiles and celestial avigation devices.

Two members of the Laboratory staff accompanied the National Geographic Society expedition to Brazil for the solar eclipse of May 20, 1947. Data assembled on this expedition together with observations made in Bikini, Maryland, New York State and Pic du Midi, France, on the brightness of the night sky were summarized in NRL Report N-3263, Unclassified.

SPECTROSCOPY (N04)

NRL's spectrographs are sometimes used to photograph the spectra of unusual light sources in unusual places. One small spectrograph has been used in Alaska, at the South Pole with the first Byrd Expedition, and also at Bikini.

During the past year this spectrograph was used on two occasions to photograph the spectra of acid-aniline and alcohol-oxygen rocket flames (NRL Report N-3097, Confidential). The information obtained in these experiments has been used in estimating the optical detection ranges of rocket missiles (see Radiometry and Photometry, Program NO6). The spectroscopic results also stimulated interest in the problem of flame temperature and the development of a photoelectric optical pyrometer adaptable to the measurement of temperatures in rapidly fluctuating flames.

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Few investigations have been conducted in the extreme-ultraviolet portion of the optical spectrum because all experimentation must be conducted in vacuum and because a suitable photoelectric means for making intensity measurements has never been developed. Radiation in the extreme ultraviolet is of importance however, in connection with studies of the ionosphere and the composition of the high atmosphere, in connection with theories of the solid state, in the operation of Geiger-Muller counters, and may also provide an additional means for chemical analysis. A program of research in this field was therefore initiated. A vacuum ultraviolet monochromator is being designed and constructed.

PHYSIOLOGICAL OPTICS (NO5)

The physiological-optics program is concerned with investigation of the properties of the normal human eye and its capabilities and limitations. Investigations during the past year have been concerned with vision in very dim light and with methods for improving vision in various degrees of darkness.

In this connection, the performance of the eye at various brightness levels has been studied, and the spherical and chromatic aberrations of the eyes of a number of observers have been measured. It has been established that these aberrations are the cause of the near-sightedness which occurs in dim light, and it was found that under certain conditions as much as a 70 percent improvement in night vision could be obtained when negative spectacles of the proper power were worn.

A study of the spherical aberration of the eye when it was focused for near objects was also made. It was found that the spherical aberration in this case was significantly different from that when it was focused for distant objects.

For the purpose of studying the eye in total and near total darkness an infrared pupillometer was developed and constructed. This employed an infrared-sensitive image tube and a special optical system and allowed the eye to be observed without illuminating it with visible light. The instrument has been of value in observing pupil fluctuations and eye movements in total darkness and dim light, and in studying the reactions of the eye to various stimuli as they occurred.

RADIOMETRY AND PHOTOMETRY (NO6)

The present photometry program at NRL has evolved from a study of the requirements of military activities carried on under the cover of darkness. Two main subjects of study have been the characteristics of vision of the human eye at low light levels and aids to activities carried on under night conditions.

It has been found that the phenomena of phosphorescence and fluorescence offer valuable means of aiding activities in the dark and the current program of research involves the study, evaluation and development of self-luminous deckmarkers, dial illuminants, fluorescent clothing and night lighting devices which will not affect the dark adaptation of the human eye. Cognate research in support of the program includes evaluation of the brightness, color and luminous durability of various materials; the investigation of fluorescence and phosphorescence; the application of photoelectric cells and the development of more accurate means of measuring the color characteristics of phosphors, paints, and optical filters. During the past year the research on luminous

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materials has involved evaluation tests of commercially developed experimental deck markers which have been submitted to the Navy. Several of these markers appear to be better than the marker types now in use.

Former methods and instrumentation for the measurement of low-luminosity radiation have been unsatisfactory. Visual methods are inaccurate due to the variable characteristics of the human eye and photoelectric methods have lacked sufficient sensitivity. The invention of the photomultiplier tube has opened a promising field in physical measurement (NRL Report N-3264, Unclassified). With this type of tube a device for registering photographically the brightness decay of phosphors has been completed and is in successful operation. Decay times from 0.001 second up to 180 minutes can be recorded.

Methods of measuring color characteristics of substances at low-brightness values have been studied and a comparison study was made of various existing colorimeters (NRL Report N-3256, Unclassified). A recording spectrophotometer using a photomultiplier tube was found to be the most satisfactory.

During the year a problem for studying the legibility of characters at low-brightness levels was undertaken. This problem contemplates the investigation of the effect of the size, color and shape on the legibility of markers, dial characters and other things which must be observed by the eye at night or under low levels of illumination. Preliminary results have been obtained and show some interesting facts in regard to vision in the dark. This study will be particularly useful in the design of airplane instrument boards and instrument-dial illumination.

The "radiometry" phases of this program are concerned with research and development work on sensitive radiation detectors such as photoelectric and photoconductive cells, thermocouples, and bolometers, and the associated electronic and optical systems by which these devices are applied. For instance invisible infrared signal lamps are employed in communication systems, and in target detection the thermal radiation emitted by the target is utilized. The program includes measurements, in the laboratory and at sea, of the intensity of sources, the optical characteristics of filters, the transmission of the atmosphere, and the emission of radiation by targets.

In the summer of 1948, NRL collaborated with the USN Underwater Sound Laboratory, New London, by measuring, from the air, the thermal radiation from the schnorkel and wake of a submerged submarine (NRL Report N-3386, Confidential). Although limited by "optical" noise from the surface of the sea, special equipment detected and also measured: schnorkel signals, which reached a maximum of 37 times noise at 500 feet and 4 1/2 times noise at 2000 feet altitude; and wake signals, which varied from 12 to 1 1/2 times noise at altitudes of from 500 to 2000 feet at distances astern the target up to 3 miles.

Measurements were made of the radiant intensities of acid-aniline rocket-motor flames which, together with the transmission characteristics of the atmosphere, permitted the estimation that detection of such rocket-motor flames at 25 to 50 miles range may be achieved by lead-sulfide-cell detection or homing systems.

Progress has been made during the year on the use of a mosaic, produced by ten small thermocouples in place of a single large thermocouple, having the same focus as the optical system of the detector. The purpose is to increase the signal due to a target and to decrease the signals due to the sky-sea background, thus increasing the

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effective detection range of a current device known as the Passive Bearing Finder (PBF). In order to use such a mosaic of detectors new amplifier circuits involving electronic switching are required. Such amplifiers for use in the PBF are nearing completion.

In connection with the sky-and-sea-background limitation problem, equipment was developed to investigate the character of these limitations. The equipment consists of a calibrated thermal source mounted on a tower in Chesapeake Bay and a special thermal detector (consisting of an optical receiver, broadband amplifier, and analyzer). This arrangement permits the investigation, in the 10-micron region, of the magnitude of the fluctuations in both atmospheric transmission and sky-sea background as a function of the frequency of fluctuation, wavelength of radiation, length and position of optical path, and meterological conditions.

Work was done on two airborne detection systems, built elsewhere and sent to NRL by BuAer for certain specialized measurements. One of these, known as the Kiel IV, employs a lead sulfide photoconductive cell as the detector and scans a field of view about 20^{0} in diameter. It works well in aircraft against targets having sufficiently high emission temperatures to radiate in the near infrared at wavelengths of less than 3.5 microns. Measurements were made of absolute sensitivity and effectiveness of the optical and electronic systems and the equipments were sent to the Naval Air Development Station at Johnsville, Pa. for further modification and airborne tests. The second system, known as the AN/ASQ5, is an infrared detector sensitive to the longer-wavelength radiation emitted by relatively cool targets such as ships or factories. It is designed to present a television-type picture of the infrared scene. Measurements of the sensitivity and of the over-all characteristics of this system are nearing completion. It has been possible to suggest a number of changes which should improve the performance of this type of detector.

The range and certainty of communication by optical radiation are limited by fluctuations in the lumination of the sea-sky background due to glints of light from waves or clouds and by the twinkling of the signal light itself. Work has begun on the problem of measuring the frequency distribution and the amplitudes of these fluctuations in order that the best choice of carrier and modulation frequencies for optical communication may be determined. To this end a special receiver (consisting of a photomultiplier tube placed at the focus of a concave mirror 5 feet in diameter) with associated amplifier and wave analyzer, has been built and measurements with the assembly are in progress at the Chesapeake Bay Annex.

A related investigation is in progress of the emission of ultraviolet, visible and infrared radiation by electrodeless gaseous-discharge tubes excited through inductive coupling by pulse-modulated r-f power, at frequencies of 20 to 100 Mc with pulse durations of 0.1 to 1 microsecond. The behavior of these light sources is being studied as function of the gas, the pressure and the frequency of excitation. The results of the two investigations will establish the feasibility of pulse-time optical-communication systems and will provide the basic information necessary to subsequent development of such systems.

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PHYSICS

ELECTRICAL AND MAGNETIC PROPERTIES (P01)

The Laboratory has undertaken an extensive program of theoretical and experimental physical research dealing with the fundamental electrical and magnetic properties of matter. One of the most promising methods of attack on this problem is the study of the interdependence of these properties at extremely low temperatures where molecular motion is greatly suppressed.

The task of attaining the extremely low temperatures required for these studies and maintaining these temperatures long enough to conduct experimental investigations is a difficult one in itself, involving the use of special precision equipment and the development of unusual experimental techniques. Temperatures in the vicinity of 4° K are attained by the use of liquid-helium cryostats which have been operated with unusual success at the Laboratory. Additional facilities are now being assembled which will make the temperature range $.001^{\circ}$ K to 1° K available for study by the use of the adiabatic demagnetization cycle. The electromagnet required for this process is rated at 100,000 gauss, draws approximately 2,000,000 watts and will be cooled by water circulating at the rate of 800 gallons per minute. When completed, these facilities for low-temperature research will be among the best available in this country.

Considerable effort has already been devoted to the design of special apparatus and the development of thermometry techniques suitable for use with the new equipment. The theory of the double-bulb gas thermometer has been investigated and a helium thermometer has been designed for use as a standard. Ordinary radio-type carbon resistors have been studied for use as possible secondary-thermometers.

Many unexplained phenomena occur at these low temperatures. For example, certain metals such as lead, tin and aluminum lose all of their resistance to the flow of electricity when cooled to a particular critical temperature. This phenomena, known as superconductivity, has been the subject of numerous theoretical and experimental investigations conducted by the Laboratory. The depth to which an electromagnetic wave will penetrate a superconductor has been investigated and a theoretical relation for the temperature dependence of penetration depth has been developed. A theoretical solution of the magnetic-field distribution about a superconducting toroidial ring has been developed and subsequently confirmed by experimental investigation. A relationship has been discovered between the temperature at which a material becomes superconducting and the Debye characteristic temperature of the material.

Other experimental and theoretical investigations intended to establish the interdependence of the electrical, magnetic, thermal and mechanical properties of matter have been outlined for future study by the Laboratory. One such study of the variation of the elastic constants of tantalum with change in temperature has been completed. The simple experimental techniques employed are readily applicable to similar investigations of other materials.

It has been found, both at NRL and at other laboratories, that materials which are superconductive at low radio frequencies lose their superconductive properties at

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infrared frequencies. Consequently, measurement of the deterioration of superconductivity of various materials at microwaves would be of possible aid in a better understanding of the phenomenon. For this purpose a series of measurements was undertaken on the conductivity of various materials at liquid-helium temperatures in the microwave region. These indicated that, at 9,000 Mc, the conductivity was about 10^6 greater at liquid-helium temperatures than at room temperatures. At lower frequencies, however, the ratio of conductivity at low temperature to that at room temperature is even higher.

One of the tactically important projects assigned to the laboratory is the search for materials which will absorb radio waves (Cf RADIO - "Absorbent Coatings"). In support of this project, work was carried on throughout the year on ferromagnetism, a subject which is imperfectly understood at present. In the hope of contributing to a better understanding of the phenomena, measurements were made of the complex permeability of ferromagnetic materials at radio frequencies in the range 50 to 1000 Mc as a function of a polarizing magnetic field.

Results on the complex permeability of iron at 1000 Mc support the conclusion that the high-frequency permeability is largely due to spin rotations. It was found that for polarizing fields greater than 50 oersteds the real part of the permeability, measured at 200 Mc and at 1000 Mc was the same, and in agreement with the static permeability over this range of polarizing field. The imaginary part of the permeability, however, is several times larger at 1000 Mc than at 200 Mc. The experiments were extended to nickel and to a study of the effects of surface treatment on complex permeability.

ENGINEERING PHYSICS OF MATERIALS (P02)

This program was undertaken to investigate, under altitude conditions, basic problems of sliding contacts in electrical apparatus. The principal aim is to determine the optimum brush and commutator or slip-ring materials for various operating conditions. Included are laboratory studies of the performance, under various ambient conditions, of commercially available brush and commutator materials and comparative tests using new or modified brush and commutator materials.

An experimental system was constructed at the Laboratory for research investigations of carbon-brush performance under simulated high-altitude conditions. The system consists of equipment for furnishing clean dry air at reduced pressure, an altitude chamber with provisions for measuring and recording voltage drop, friction and temperature, and instruments for measuring and controlling pressures and air flow (E-3176, Unclassified). Indications are that the machine constructed at NRL will provide valuable information that will aid in the solution of the high-altitude brush problem.

Additional research on this problem included an investigation of the performance of tungsten-cobalt plated slip rings and commutators (E-3211, Unclassified). An electroplated alloy of tungsten and cobalt on copper was given limited tests under sea-level and simulated high-altitude conditions. The first series of tests, made with a slip ring and a dummy commutator under conditions of low temperature, humidity, and pressure, gave results which were favorable when compared to results on copper. Further tests of an actual aircraft generator at sea level were not satisfactory. Work is continuing.

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ATMOSPHERIC ELECTRICITY (P03)

One of the greatest natural hazards to the all-weather operation of naval craft, particularly airplanes, is the interference with radio communications by atmospheric-electrical phenomena. The major purposes of this program are to eliminate the dangers introduced by this "precipitation static", and to study other electrical phenomena connected with thunderstorms, snow, fog, or similar conditions (P-3199, Unclassified). Basic research conducted under the leadership of NRL scientists during the war did a great deal to clarify this problem, but the task of developing eliminative instrumentation has proved difficult.

The provision of antenna hardware which will reduce aircraft precipitation static has been particularly perplexing. The assembly of units called "antenna hardware" includes the antenna wire, lead-through and dead-end masts, Tee splices, Vee connectors, tension units, and strain insulators. Because of its simple geometry, electrostatic shielding for the wire is easily provided by a plastic coating. Development of satisfactory models of the other units has been more difficult. During the Fiscal Year 1948, NRL completed the development of masts in which the desired electrical and mechanical strength properties are satisfactorily combined and arrangements were made to produce these masts in quantity. Advances were made toward completion of the remaining units, so that the entire antiprecipitation-static-hardware program has shown substantial progress.

HEAT POWER (P04)

In connection with the Heat Power program, model pulse-jet engines have been set up in a small laboratory at the Chesapeake Bay Annex. Studies of the operating efficiency of these models have outlined clearly the regions of study most likely to result in substantial improvements (0-3064 and P-3252, both Confidential). A large decrease in fuel required per pound of thrust (or large increase in efficiency) was shown to be obtainable by use of the bell form of tailpipe outlet. Over-all proportioning of these engines was shown to favor a straight-tube design. In fact, the simpler and more economically constructed pulse jet of straight-tube form proved far more efficient than the original German V-1 form. The magnitude of the fuel-rate-per-unit-thrust improvement obtained is unusual in engine studies.

METEOROLOGY (P05)

This program was established to make provision for the requests received from time to time for development or study in the field of Meteorology. In general it covers the conduct of research leading to special meteorological instruments which will be more accurate and more rapid in their response to atmospheric temperature, pressure and humidity.

In conncetion with a concurrent radio-research problem, having to do with the attenuation of radiation by rain, the development of an instrument which will measure the size and distribution of raindrops was requested. In answer to this request the "aircraft disdrometer" was developed. This optical-electronic device, used to measure sizes and distributions of raindrops from an airplane, was designed, built, and then flight tested under severe conditions in Panama for a six-week period. It is sensitive to drops in the range of approximately 1/2 millimeter in diameter to the maximum drop-size which can exist in the atmosphere -- about 7 millimeters.

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The need for more accurate information about atmospheric moisture resulted in another new instrument which was developed to measure and record the extremely small rates of flow which result when total liquid water in clouds or rain is measured. It consists of a novel four-way metallic stopcock, solenoidally driven, and a section of 1-mm-bore capillary tubing in which the flow is measured.

For several years, the Navy has been operating a system of tripartite seismograph stations in the Caribbean and Pacific for the purpose of detecting the presence and direction of hurricane or severe storm areas. The present equipment installed in these stations photographic recording of the seismic activity, which delays the examination of the record many hours. The instrumentation problem involved in speeding up the sensing and direction-finding process was presented to NRL. It was believed that it might be solved with the aid of electronic techniques. Such apparatus has been devised and is now being perfected. A tripartite station is under construction at CBA which consists of three pendulums sensitive to a horizontal component of the earth's motion. Coils attached to these pendulums move through a fixed magnetic field and thus generate voltage proportional to the velocity of the earth's motion. This output voltage is magnified by amplifiers designed to pass signals of extreme low frequency. The amplifier output is applied to a commercial pen-writing recorder, thus making an ink-on-paper record for immediate observation. The three pendulums form an equilateral triangle with sides of about 2,500 feet. The phase difference in the earth's motion as it crosses over these three pendulums is analyzed electronically and a direction of approach automatically indicated. In this way, the direction of a disturbance can be known within a matter of seconds after the signal has been received. It is expected to be a decided improvement over the photographic-recording and graphical-analysis technique.

UPPER ATMOSPHERE (P06)

In 1946 the United States acquired from Germany a number of V-2 rockets and established a proving ground for rocket experimentation at White Sands, New Mexico. The Naval Research Laboratory's interest in these rockets and their flight has been in the use of the high-altitude vehicles as airborne laboratories for fundamental research on phenomena of the upper atmosphere (R-3171 and R-3358, both Unclassified; and R-3236, Confidential).

Rockets and Rocket Services. — The Laboratory has been the primary research agency in nine V-2 flights, and has conducted experiments in six additional V-2 flights. It designed and arranged for the construction by the Naval Gun Factory of all research warheads which have been employed in the V-2 rockets fired at White Sands. Anticipating the eventual exhaustion of the supply of V-2 rockets, the Laboratory initiated and prosecuted development of the RTV-N-12 "Viking", a high-altitude-research rocket. This rocket is being constructed by the Glenn L. Martin Company and its power plant is being built by Reaction Motors, Inc. Preliminary calculations indicate that the RTV-N-12, weighing 10,000 lbs when fueled, will carry a 500-lb payload to altitudes between 150 and 200 miles. The Laboratory also participated in the procurement of the RTV-10 ("Aerobee"), a booster-launched high-altitude sounding rocket developed by Aerojet Engineering Corp. and Douglas Aircraft Corp. under contract with the Bureau of Ordnance. NRL will employ a total of five RTV-10 rockets for high-altitude research in the Venus phase of the Aerobee program. The Laboratory furnished the major portion of the research instrumentation for three V-2 flights during the past year. Only one of these flights was successful. The rocket performed erratically during each of the remaining flights, and as a result, most of the experiments

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yielded no data. The Laboratory also conducted a limited amount of research in two other V-2's. One of these flights was successful. The other was a failure due to an explosion which occurred early in the flight.

Electronic Instrumentation and Services. — The provision of adequate means for the recovery of data was one of the chief problems which arose at the outset of the rocket-sonde research program. Radio telemetering was chosen as the principal method for relaying data. A telemetering system was designed and 35 units were constructed by the Raytheon Manufacturing Company under a crash program. The system was ready in time for the first research firing on 28 June 1946. Since then it has been used on 28 V-2 flights. This telemeter system employed pulse-time modulation, operated on 1,000 Mc and provided 23 channels, each with a sampling rate of 192 cps. Effort was then directed toward the development of a new telemetering system. Several major design improvements were made, notably, the provision of a time reference for each channel and the use of direct video recording. A circularly polarized quadrupole antenna and greater radiated power were provided. The number of channels was increased to 30, and the sampling rate was increased to 312 cps. Seventy of the new units are being constructed by the Hazeltine Electronics Corporation. The new system was used for the first time on 19 April. Further tests will be necessary to evaluate its performance completely.

Ionization. — The propagation of radio waves through the jet exhaust of rockets has an important effect upon the radio control and detection of these missiles. It also is a governing consideration in the use of radio telemetering for obtaining rocket performance and upper-atmosphere-research data. To study this matter, attenuation measurements were made at the frequencies of 1,000 and 10,000 Mc during the V-2 flights of 10 July, 22 January and 19 April. Measurements of attenuation were also made at 30,000 Mc during the last of these flights. In all these flights, indications of an increase in attenuation with altitude were found. The attenuation levels at X-band and K-band were found to be somewhat greater than 15 db per meter. The L-band attenuation followed the same general pattern as the X-band attenuation; it was smaller in magnitude, however, by about a factor of two.

Cosmic Rays. — Cosmic-ray phenomena have been extensively studied for several decades at altitudes ranging from below sea level to 25 km above sea level. This research has indicated that the effects at these altitudes are largely caused by secondary cosmic radiation. Hypotheses have been put forward concerning the nature of the primary radiation and of the processes involved in the creation of the secondaries. Lack of experimental evidence about either of these points has been one of the principal obstacles to a complete understanding of the subject. Accordingly a series of V-2 cosmic-ray experiments was begun. Seven experiments have been conducted with Geiger-counter telescopes. These have led to the conclusions that: 1) Electrons do not form an appreciable fraction of the primary radiation; 2) soft, secondary circulating electrons are present above the atmosphere; and 3) the primary radiation gives rise to a multiplicative process in the upper regions of the atmosphere. One of these counter telescope experiments was conducted in the V-2 fired on 2 April. In addition a cloud chamber was operated successfully during the 22 January flight, when for the first time photographs of cosmic-ray events were taken above the earth's atmosphere. One of the photographs shows an ionizing primary particle, which demonstrates that particles heavier than protons exist in the primary radiation.

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Ionosphere. — Radio-pulse techniques have been used extensively for several decades to study the ionosphere. The interpretation of the data obtained from these measurements, however, requires the making of certain assumptions which are directly associated with the fact that this work is carried out at the ground level. Consequently, a series of experiments has been conducted from within the ionosphere itself by means of V-2 rockets. An analysis of data obtained during the 7 March 1947 V-2 flight showed that the region of radio fadeout occurred between 65 and 75 km altitude. A propagation experiment, a positive-ion collector and a generating voltmeter furnished data simultaneously during the V-2 flight of 22 January 1948. The actual distribution of electron density as a function of altitude was determined from the propagation measurements. This distribution exhibited a sharp gradient which gave direct evidence concerning the nature of the sporadic E-layer. The generating-voltmeter data indicated that photoemission effects associated with the solar radiation occurred above 90 km altitude. Information derived from a correlation of all the data obtained during this flight showed that the ratio of the ion density to the electron density at the E-layer maximum was approximately one hundred.

Pressure and Temperature Studies. — The objectives of this phase of the high-altitude research program are the determination of pressure, density and temperature of the earth's upper atmosphere. Since ambient pressure and temperature may both be calculated from appropriate pressure data, a series of pressure measurements was begun. In addition, the temperatures developed at various points on the missile itself have been recorded during flight. The objectives were realized to a limited extent in the V-2 flights conducted during 1946. Pressures and skin temperatures were measured directly up to an altitude of 70 km. Atmospheric pressure and temperature were determined for altitudes up to 120 km from the data obtained during the flight of 7 March 1947. Pressure measurements were made up to an altitude of 128 km, and temperatures were determined accurately up to 70 km, during the V-2 flight of 22 January 1948. The results of this research show that the pressures below 60 km altitude are slightly lower than those predicted by the NACA tentative standard, and that in the 110 km region the pressure is lower than the predicted value by a factor of ten.

Spectroscopy. — Three solar ultraviolet spectrographs were fired in V-2 rockets during the past year in a further attempt to extend the solar spectrum below the limit of 2150 A reached with the V-2 flight of 10 October 1946, and to measure the vertical distribution of ozone and possibly also of oxygen. The flights of 8 October 1947 and 2 April 1948, yielded spectra which were of value in the Fraunhofer analysis. For the flight of 19 April 1948, a stabilizing mechanism, referred to as a "Sun-Follower", was developed. This mechanism kept the spectrograph obtically aligned with the sun during flight by turning it about two axes in accordance with the error signal provided by an optical scanning device. This should have permitted the extension of the solar spectrum to a much shorter wavelength, but the rocket flight was a failure, and the equipment was lost.

PHOTON AND PARTICLE COUNTERS (P07)

This program covers the research, development, and application of Geiger, crystal, proportional, and ion-chamber counters with interest in the counting characteristics of gaseous mixtures, temperature-insensitive counters, low-voltage counters (N-3189, Unclassified), high-efficiency and directional gamma-ray counters, proportional alpha-particle counters and scintillation counters.

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Included under this program are studies of methods of detecting and measuring X-ray and nuclear radiations (N-3265, Unclassified). In connection with the radiological-safety program of the Bureau of Ships, special types of counter tubes "BS-1", "BS-2", and of corona-regulator tubes "BS-101" were developed. Specifications were written for large-scale manufacture of these tubes and considerable effort has been expended in perfecting manufacturing techniques. A counter tube was developed which delivered a large enough charge per pulse to permit measurements directly on standard microammeters without benefit of electronic amplification. Proportional-counter studies led to the development of an improved sealed-off tube for use in an alpha-beta-gamma survey instrument.

Further investigation of non-electronic dosimeters (radiation measuring instruments) led to improvements in coloration types of dosimeters based on the use of alkali halide crystals. New activation treatments yielded a tenfold increase in sensitivity and a corresponding improvement in stability. At the present stage it appears possible to make a satisfactory personnel dosimeter for exposures of 5 roentgens and greater.

A better understanding of the properties of diamonds as crystal counters was obtained from a study of a large collection of "counting" diamonds. At the same time several scintillation counters were investigated and a number of promising fluorescent materials were studied.

ELECTRON MICROSCOPY, ELECTRON, AND X-RAY DIFFRACTION (P08)

For this program NRL maintains a group of laboratories in which operations are carried out with a variety of instruments such as electron microscopes, X-ray-diffraction spectrometers and cameras, and electron-diffraction cameras for ultimate structure determinations. The special staffs of these laboratories carry on basic research on the structure of materials and also act as a service group to apply these techniques for the benefit of other sections of the scientific organization.

An electron-diffraction camera of improved design was completed and is being applied to studies of gas-diffraction patterns. A theoretical treatment was worked out to utilize the improved experimental data in interpreting electron-scattering patterns of molecular vapors. The theory can now be applied to the determination of molecular vibrational amplitudes as well as average bond distances.

X-ray fluorescence spectroscopy was applied to analyses of metals, solutions, minerals, and plastics in various cooperative problems and with other Government departments. The methods developed are particularly useful in many problems of interest to the Atomic Energy Commission.

A study was pursued of the structure and oxidation chemistry of evaporated metal films by means of electron microscopy and resistance measurements.

CRYSTALS (P09)

The activities in nonmetallic crystals embraced a broad range of projects having the general goal of improving the components in radar, sonar, and optical devices. The most important projects included piezoelectric crystals and ceramic bodies for sonar gear, materials to transmit and filter infrared and ultraviolet radiation for opti-

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cal devices, and luminescent materials. One of the most important parts of the program is the development of ways of growing synthetic crystals.

Because little progress can be made in many of these fields without basic research, several of the projects completed during the past year were fundamental in nature. Notable was the intensive investigation of the phenomenon of photoelasticity, in which several new materials were examined and the relations clarified between strain optics and atomic polarizability. It was shown for instance, that there is a close relation between the strain polarizibility and the type of bonding in the crystal as measured by other properties. Among the crystals studied were various gem and industrial diamonds, and many of their disputed properties (as crystals) were clarified. Concurrently, an important contribution from infrared work was the suggestion of a new mechanism for the coupling of vibrations. This is based on the idea of the change in polarizibility with strain during vibration and is in better agreement with the data than the accepted picture based on anharmonic forces.

Another contribution to pure physics was concerned with dielectric breakdown. This resulted from a careful study made of the paths at which breakdown occurs in alkali halides under various conditions and with various compositions and textures. As a correlary of these studies it was clearly demonstrated that the ammonium phosphate crystals can never be the limiting factor when used in sound gear in the present system of oil-filled projectors.

A similar basic study was an investigation of mechanical properties, particularly of stress release, and of the slip and flow induced by percussion figures. The work resulted in a method for orienting crystal specimens of thallium halides (which are not amenable to X-ray techniques), and in techniques for removing strain figures from optical specimens.

Basic to all of the work under this program is the development of improved techniques for preparing crystalline materials with closely controlled composition and structure. The need for this type of research is demonstrated by the constant stream of requests from other laboratories for crystal specimens and for information regarding methods of preparation. One achievement in crystal growth was the recently developed lithium sulfate crystals, which have important applications in sound gear, but which presented unusual growth difficulties. The solubility characteristics are such that the usual temperature-lowering processes cannot be used, the solution has a tendency to creep, and the crystals have a strong tendency to crack. By means of a controlled refluxing of the equilibrium vapor, all of these difficulties were eliminated.

With hydrothermal synthesis, which involves aqueous solutions at high temperatures and pressures, exploratory work was done on several piezoelectric mineral substances but the emphasis was on synthetic quartz. Successful growth was demonstrated on a small scale but efforts to develop a large-scale growth process have been made at NRL.

A majority of requests for crystals, both from within the laboratory and from outside, were for materials grown by the conical-crubicle-melt process. These included isotropic materials useful in optical applications, and the simple compounds amenable to solid-state theoretical studies. Refinements in this technique made possible the synthesis of several previously unobtainable crystals such as lead chloride, cuprous chloride, and a number of common alkali halides with heavy metal inclusions.

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As part of the program to secure improved materials for the piezoelectric elements in sonar transducers, an exhaustive survey of crystal materials, was completed (S-3187). The results were disappointing because the survey demonstrated that no crystals available at the present time can improve appreciably the performance of sonar transducers. One material, iodic acid (HiO_3), has properties comparable to the ammonium phosphate now used in transducers; a much higher cost, however, discourages its adoption.

The infrared instrumentation was improved during the year and a number of materials investigated. The most complete study was that of the infrared reflection and absorption characteristics of MgO which showed that the previously accepted curves obtained for this material by other workers are incorrect and that extensive fine structure is not present and that MgO does not differ greatly from other crystals of NaCl structure.

In the field of luminescent materials progress has been made in investigations of fundamental principles. Beginning with a study of phosphors of alkali halides and of calcite the role of the necessary impurity ions has been clearly demonstrated for a large series of the commercially important materials. A theory of "sensitized" luminescence, has led to the discovery and development of several new highly efficient phosphors.

APPLIED MATHEMATICS (P10)

The applied mathematics work during fiscal 1948 was along two lines: (1) Obtaining field data from shock trials conducted aboard the naval transport USS NIAGARA, and studying applicable methods for analysis of such data, and (2) studying computer facilities and methods of mathematical analysis generally applicable to research activities in mechanics. As one result of the latter activity, a purchase contract for an analog computer was completed which promised delivery in the fall of 1948. Work was also done leading to an improved method for absolute calibration of electromechanical pickups. By this method, if two linear indicators are given, one of which is bilateral, the sensitivities of the units can be established in both magnitude and phase by three experiments which do not involve the direct measurement of oscillating mechanical quantities. The technique does not depend upon the specific designs of the units (F-3337, Unclassified).

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RADIO

RADIO COMMUNICATION (R01)

The Radio Communication program at NRL embraces communication-systems analysis and development, frequency stabilization and measurement, interference studies, facsimile and graphic communications, antenna studies, circuit and equipment development as necessary to implement the systems work, and finally, a due proportion of technical evaluation or analysis of specific equipment.

In order to provide guidance in the choice of the type of modulation best suited to the needs of the Navy, a comprehensive investigation of the relative performance of an amplitude-modulated and a narrow-band frequency-modulated UHF communication system was carried out. Every effort was made to insure that the investigation was as thorough and careful a comparison of the two basic methods of modulating a radio wave as could be devised. A mathematical study (R-3213, Confidential) was undertaken to determine the applicable theoretical limits. The communication equipments employed were carefully selected and the design and performance characteristics were thoroughly analyzed to determine their capabilities and limitations (R-3232, Restricted). Laboratory studies and measurements of unusual thoroughness, employing specially developed instrumentation, were devised and carried out (R-3233, Restricted). Operational shipboard trials and airborne trials were conducted (R-3234, R-3235, Restricted). This analytical program resulted in a large volume of significant information from which it is concluded that a.m. is generally preferable to f.m. for the highly mobile conditions characteristic of naval service, from the standpoint of both performance and the physical requirements and limitations of the equipment (R-3230, Restricted).

Another modulation study was undertaken to determine the relative bandwidth requirements for the transmission of intelligence by f-m and a-m waves. Mathematical derivations of the side-band distribution for several modulating-wave shapes were obtained, as well as a graphical method which permits the solution of most modulating-wave shapes (R-3154, Unclassified). It was shown that, in selecting the types of modulation for a given service, many factors must be carefully balanced. Functions requiring large dynamic ranges and large signal-to-noise ratios may indicate a preference for f.m. with relatively large shifts. Other functions which can tolerate rather large amounts of interference may require narrow shifts. In other cases a.m. will be preferable. The interesting possibility that f.m. may produce less interference bandwidth than a-m transmission was demonstrated when the modulating function contains discontinuities and transients with high harmonic content. This work was an inherent part of a facsimile-transmission project, but the results are quite general in application.

The general study of the systems and methods of transmitting graphic material by radio required a detailed analysis of equipment, operational procedures peculiar to Navy conditions, propagation and noise, and other factors entering into the process. The insistent demand for improved facsimile in the naval service, particularly with

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respect to reliability and flexibility, indicate that present systems will have to undergo relatively great changes in order to attain the desired results. A search has been conducted for methods of transmission less subject to errors caused by noise, multipath and distortion introduced by the radio path. It has been possible to formulate conclusions in regard to optimum modulation conditions, with due consideration of operational requirements and circuit difficulties. Studies of the conversion and demodulation portions of the system have permitted considerable improvement to be effected by the reduction of distortions caused by narrow-band limiters and intermodulation. A circuit development was evolved which permits variable-speed operation of the apparatus so that the fastest transmission speed consistent with receiving conditions can be selected. All of the above information or improvements are now being utilized by the Naval Communication Service.

In the transmission of high-speed facsimile over long radio paths, the multipath effect is the limiting factor on speed and quality. To combat this effect without slowing transmission a multi-channel multiplex system has been devised. By commutating between the eight channels provided, sequential information can be fed to the facsimile terminal equipment at eight times the individual channel keying rate. The longer signal units are less susceptible to loss of identity by multipath effects. The advantages of these principles were demonstrated operationally and are being incorporated into current specifications.

DETECTION (R02)

In the detection field efforts are directed to provide new and improved detection systems with increased volumetric coverage, resolution, position accuracy, target capacity and perception, and decreased vulnerability, with provision for moving target indication, target interpretation and designation.

The detection of approaching enemy aircraft and guided missiles is vital to a successful air defense. The early location of rapidly moving targets permits their courses to be plotted and allows sufficient time for the initiation of effective counteraction.

Search radar equipment requires further intensive development to meet the new demands created by the greatly increased speed of postwar airborne vehicles. A long-range system is under development by the Laboratory to meet requirements specified in memoranda issued by the Chief of Naval Operations. These requirements contemplate a radar capable of detecting a guided missile having an effective cross section of one square meter at heights up to 15 miles out to a range of 300 miles with 360° azimuth-scan every six seconds. To satisfy these specifications it was determined that a multiple-beam system was the most economical in weight, size, and power. However, the problem of obtaining six or more overlapping beams from a single reflector has been one of the most difficult of those encountered in this development. Antenna studies for this long-range radar system have resulted in the derivation of basic design curves for multiple-beam antennas and have demonstrated the feasibility of the multiple-beam scheme for attaining wide coverages.

One approach to the problem of obtaining multiple overlapping beams has achieved usable results. The method consisted of altering the contour of the dish or tapering its reflectivity and has permitted seven beams with 2-db cross-over points and 17-db vertical side lobes, all obtained from a single dish. Design data for a 35- by 14-foot

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antenna of this type have been determined, and the specifications have been given to the Raytheon Manufacturing Company, the builders of an experimental model. Another approach to this problem of generating multiple over-lapping beams from a single reflector offers promise of better quality beams with lower side lobes. This arrangement consists of a paraboloid reflector split horizontally at the center with the two sections separated by a flat strip about one wavelength wide.

The multi-lobe coverage patterns proposed for this radar system, in addition to providing the coverage rate required, can be used to give target-altitude information. A study of this feature indicates that the measurement of target elevation angle to an accuracy of ±25 min (for angles above 1.5°) is possible, and position accuracy anticipated in azimuth and range is ±18 min and ±200 yd respectively.

In addition to the problem of long-range search, there is an urgent requirement for detection with certainty of any aircraft at elevations up to 80° and within a range of 15 miles. This need became evident during the latter phases of the World War II Pacific naval campaign---small enemy planes were able to penetrate the radar screen without detection when flying at very high or very low altitudes, especially when approaching over land. To fill this gap in detection coverage the "hemispheric radar" has been under development.

The planning stage for the hemispheric radar has been completed and work has progressed on all major system units. The antenna for this system poses many problems and the "dual Foster scanner" has been proposed as offering the most likely solution. This scanner, mounted together with a reflecting dish on a rotating base stabilized against roll and pitch of the ship, produces two narrow, pencil-like beams, each of which repeatedly scans rapidly through its vertical-angle sector while being rotated, more slowly, in azimuth.

The problem of suitable indicators ranks with the antenna problem as one of the major concerns involved in the development of the complete hemispheric radar system. A master indicator, which will display all information provided by the radar in a readily interpretable form without sacrificing its three-dimensional character is being considered. In one display of this general type, echoes appear as luminous spots on a rectangular coordinate plot with the abscissa representing target bearing and the ordinate indicating elevation angle. Distance is indicated approximately by lateral elongation of the echo spots in an amount inversely proportional to the range of the corresponding target. Another master display, still in a relatively early stage of development, is being designed to show the radar coverage in an isometric pattern on the cathode-ray-tube face. This pattern will present the entire radar coverage or, for further accuracy, a smaller segment somewhat enlarged. For still greater accuracy in determining target coordinates, the device will permit rotation of the pattern to enhance the observer's view of the desired target. It is intended to make use of a memory tube in the display system to permit storing radar information in order to increase the brilliance of the display, to eliminate flicker, to permit control of image-persistence time and at the same time provide a large display screen and moving-target indication features. Signal storage appears to be a prerequisite to good three-dimensional display. Considerable work with experimental models of the Haeff "memory tube" has demonstrated successful sequential erasure and writing speeds of the order of 10,000 inches per second. Experiments have been made on the dependence of persistence time upon the area occupied by the signal on the storage surface; there is evidence that larger signals have greater persistence than the smaller

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ones. Storage with adequate resolution for radar indicator use has not yet been achieved, however.

A study of the system requirements for (radar) fighter direction from a picket ship was started late in the year. At the present stage of this study two important conclusions seem evident: (a) The requested 2-second scan rate (originally thought to be the lowest tolerable) limit is not required -- six-second scanning (with suitable computers and AI radar) appears to be sufficiently fast and probably cannot be exceeded if the equipment is to have high accuracy and long range and yet be installed on destroyer-size vessels; and (b) The multi-lobe vertical-pattern type of coverage appears most economical in weight, size, and power requirements, all of which are important factors on small-ship radars. Further work on the computers for tracking while scanning will be required before the radar system parameters can be determined.

Tactical experience with conventional radars has often brought out the difficulty of detecting moving targets in the presence of severe clutter, as in attacks on surface vessels by planes approaching over land at low altitudes. Moving-target-indicator (MTI) systems operate on the principle of echo phase comparison from pulse to pulse in order to cancel pulses from stationary targets. To maintain an optimum relationship between velocity and response, a fixed ratio of radio frequency to pulse-repetition frequency must be approximated. To remove this limitation, which becomes onerous at frequencies above 400 Mc, a double-pulse method of MTI has been conceived. In this the time spacing within pairs of pulses determines the velocity-response curve (which could then always be optimized) and the spacing between pairs is determined by the maximum range desired. Circuit design and components for applying MTI to the SR-3/6, AN/SPS-6 radars were completed. This system is somewhat similar to that provided by NRL for the SC/SK radars, but (because of the higher frequency) it requires an additional unit for correcting for ship's motion.

To provide urgently needed information on the detectability by radar of small targets - such as schnorkel - in the presence of sea clutter, simulator equipment was built so that measurements of detectability as a function of system parameters could be made in the laboratory (R-3301, Confidential). In conjunction with studies made by Operations Evaluation Group of CNO, an investigation was made to determine the effect of antenna rotational speed on signal detectability for a plan-position indicator. In this study, the ratio of pulse repetition rate to rotational speed was held constant to produce 25 pulses per target per revolution, and all measurements were made using a simulated sea-return noise background. Results indicated a linear increase in signal detectability from 5 to 25 rpm, and very little increase above 25 rpm. Optimum system parameters to be employed in an airborne radar designed for detection of schnorkel were also investigated by this simulator technique. Results indicated that an antenna rotational speed as low as practicable should be used, that the antenna beamwidth should be approximately 3 or 4 degrees, that the pulse length should be as short as possible, and that the pulse repetition rate should be as high as possible. These results have been used as a basis for preliminary specifications of a schnorkel-detecting radar.

IDENTIFICATION (R03)

Program material under this subject is largely classified as Secret, and therefore a proper account of work done during the year cannot be provided in this report.

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NAVIGATION (R04)

The peculiar problems involved in the navigation of naval aircraft include not only the problem of point-to-point avigation over trackless areas of water, but also the complex task of guiding large numbers of aircraft back to their mobile bases--often in darkness or thick weather. Thus, two long-term projects undertaken at NRL are of wide interest to the Navy. One of these is the NRL Carrier Controlled Approach (CCA) System; the other is a consideration of the multiple problems involved in aircraft-carrier all-weather flying (CAWF). Other avigational problems underway during the past year sought the improvement of long-range-navigation systems and a better ground-velocity indicator.

The CCA system has been installed aboard the carriers, USS VALLEY FORGE, (CV-45), and USS PHILIPPINE SEA, (CV-47) so that the experimental equipment could be tested, under typical operational conditions and under the guidance of experienced personnel. The first series of evaluation tests was conducted on the VALLEY FORGE and the system was shown to be capable of making foul-weather landings possible. The PHILIPPINE SEA installation was completed more recently. Preliminary evaluation tests, with NRL engineers participating, were conducted successfully while that ship was overseas. As a result limited production of the CCA equipment for continued fleet evaluation has been initiated by the Bureau of Ships.

A survey and technical evaluation of all existing techniques applied to or proposed for the solution of the problems of aircraft carrier all-weather flying has been completed (R-3164, Secret). The CAWF program will require the development of an integrated system for the control and navigation of aircraft flight from take-off, through mission, and return to base. The survey has been coordinated with the planning for and presentation of a Navy all-weather flying program to be recommended by the Office of Naval Research.

The Chief of Naval Operations has placed much importance on the CAWF program and has assigned to the Bureau of Aeronautics prime responsibility for its pursuance. NRL has been given responsibility for research in the field. One step planned under the CAWF program is to apply elements of the Data Relay Navigation System to the Carrier Controlled Approach System. CCA is a "talk-down" approach system wherein the aircraft position is observed on a radar scope aboard the carrier, and voice communication with the pilot is used to control aircraft speed and flight path. It is proposed to supplement voice communications by relaying the ship's radar scope indication of aircraft flight path to a monitor-indicator in the aircraft. Also under study is the adaptation of radar beam-rider or command control, using tracking or tracking-while-scanning radars, for automatic approach and landing of carrier aircraft. Maximum use is being made of components of the air-and-shipborne "Cadillac" system in the development of DARN. Models of some of the functional units for a laboratory model of the system were constructed and the required Cadillac-component modifications completed during the reporting period.

The development of an airborne light-weight homing system has been completed. Airborne components consist of a self-contained lobe-switched transmitter and receiver, and an indicator from which ranges between 0 and 200 miles, and home-ship-position angle relative to line-of-flight, can be read (R-3271, Confidential). It is estimated that production units of this equipment should weigh approximately 35 lb, require about 200 watts of power, and operate to line-of-sight range.

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Toward the solution of another type of navigational problem, fundamental studies and investigations were conducted on new systems for more effective long-range navigation. A study of pulse-shape requirements for low-frequency systems was completed, including (1) distortion effects encountered in transmission through the system (R-3288, Confidential) and (2) pulse matching considerations (R-3160, Restricted). Techniques were developed for measurement of the sideband components of pulse transmissions, and the optimum pulse shape for minimum interference from a navigational system was determined.

Research and development of a ground velocity indicator, to be used for determining the absolute velocity of an airplane relative to the earth's surface over which the airplane is in flight, has been in progress for several years. Results to date indicate that a satisfactory basis for such a device is provided by obtaining the velocity from the Doppler frequency shift which occurs when microwave radiation from an airplane-borne radar is scattered by the earth's surface and returned to the airplane. An experimental c-w system, operating at approximately 9,000 Mc, having a power output of 15 milliwatts and a single antenna with a gain of 30 db, was used in numerous flights of a four-engine Navy bomber (R-3239, Confidential). The error in ground-velocity indication during these trials was less than two percent in all but one case. To obtain a quantative measure of the ultimate possible accuracy of such a system, an accurate spectrum analysis of typical Doppler frequency-shifted signals has been undertaken. One of the most serious difficulties encountered has been the presence of spurious signals which are caused by undesired frequency modulation of the transmitter tube. To study and evaluate this effect it was necessary to develop and build elaborate measurement apparatus; this equipment will find further use in studies of the frequency output of transmitter magnetrons. One of the by-products of work in this subject was the development of a device for indicating distance traveled by an airplane, computed from ground velocity and time.

Also included in the NRL Navigation program, and as an adjunct to the rescue program for disabled submarines, an emergency radio buoy has been devised to facilitate locating the submerged vessel. Upon ejection from the submarine the buoy rises to the surface and automatically transmits distinctive radio signals. The design is capable of withstanding pressures encountered at depths of 1000 feet.

CONTROL (R05)

As the complexity of instruments applied in modern warfare increases, it becomes more and more necessary that as many operations as possible be made automatic. The Naval Research Laboratory has undertaken extensive work in the control field. This work is principally directed towards the development of integrated systems for the automatic control of gunfire and the guidance of missiles, and includes the development of techniques and equipment for the taking of and analysis of equipment-performance data.

Gunfire Control.--The Laboratory continues to be actively engaged in the evaluation of gunnery fire-control systems. The performance of existing and of new fire-control systems is investigated to determine tracking capabilities, vulnerability to jamming, and accuracy, as a measure of the suitability of such equipment for fleet use. Such evaluations normally result in recommendations and the development of prototype equipment designed to improve the performance of gunfire-control systems (abbreviated GFCS). For example, main-battery gun turrets oscillate excessively in

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train under certain conditions, particularly, when operated in automatic control at sea. It was desirable that corrective measures be found which would not involve major alteration of the system. As a result of investigations, conducted at the Chesapeake Bay Annex and aboard the USS MACON (CA-132), NRL radio engineers designed and built a compensating servo mechanism to replace the director train receiver in the Rangekeeper Mk 8. This servo has been undergoing tests at CBA to determine its effectiveness in reducing the oscillations of the main-battery system so that the system instability while in automatic control will be minimized. An operational evaluation at CBA of the Radar Mk 25 Mod 2 operated with the Gun Director Mk 37 and Computer Mk 1 was completed and cooperative assistance was provided for the Bell Telephone Laboratories test of the Radar Mk 25 Mod 2 in connection with the development of a new GFCS Mk 65. Operational evaluation of the GFCS Mk 63 Mod 10 at CBA is continuing. The Radar Mk 40 (a new target-acquisition radar developed by NRL and Raytheon Co.) was installed at CBA and preliminary operational tests of this system were completed. The Laboratory assisted the General Electric Corporation in the installation and trouble-shooting of GFCS Mk 56 at CBA. A pre-production model of the GFCS Mk 56 was installed and put into operation by November 1947. This system could not be maintained in operating condition because of component failures and it was replaced by a production model of the system delivered to CBA in March 1948. It is expected that the operational evaluation of the Mk 56 will be finished during the next reporting period. Meanwhile a type test of Radar Mk 25 Mod 2 was completed. A considerable saving of time and money was effected in the Mk 25 Mod 2 type test by combining the usual temperature, humidity, and vibration tests conducted by the manufacturer with the official Navy tests.

Computation.—Operational evaluation of fire-and missile-control systems is excessively expensive in the manhours required for data processing and analysis. Conventional data-recording methods now applied at NRL require the photographing, approximately ten times a second, of many calibrated synchro-driven dials which indicate the variables in the fire-control problem. Data from the film are transcribed onto data sheets, then manually recorded upon teletype tape so that necessary computations can be performed by the Digital Computer Mk 22 (R-3177, Restricted). The development of automatic machinery to perform these tasks was therefore initiated. A new system proposed by NRL, called DIGITAR, will consist of digital converters (one for each channel to be recorded), a recorder and a transcriber. The converter will measure the angular position of a shaft (servo driven from a synchro signal in the present application) to five significant figures by producing, through photoelectric means, an electrical output in the form of a binary-coded representation of the decimal number corresponding to the shaft position. The recorder scans the electrical output of each digital converter and stores the information sequentially on a recording medium from which the transcriber may transfer the data to a teletype tape in a form suitable for insertion into the Computer Mk 22. Both the digital converter and the recorder may be operated at repetition rates of ten times per second or higher, but the transcriber will operate at a much lower rate, depending on the capability of the teletype punch. An initial design model of the digital converter has been constructed and successfully operated in the Laboratory. Photographic- and magnetic-storage methods are being explored for application in the recorder unit. It is expected that the basic problems of the system will be solved within the next reporting period so that a contract can be negotiated for commercial construction of a prototype model (R-3340, Confidential).

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As a result of a recent Laboratory survey of computing needs, and computer availabilities, it has been decided to procure and staff at NRL a large-scale digital computer for use in general computing problems arising at the Laboratory.

Missile Guidance and Control.—The problem most difficult of solution in the development of short-range guided missiles is that of automatic guidance. The mid-course short-range missile-guidance systems now being most actively developed by the Naval Research Laboratory are the WASP beam-rider system (whereby the radar beam provides a track to be automatically followed by one, or several missiles at the same time) and several varieties of the HORNET command-guidance system (in which motions of the target and the missile in space are measured, and a computer generates guidance commands which are applied to reorient the flight path of the missile). Investigation of these two general guidance systems, together with a number of related basic and applied research problems, is one of the more important projects of the Naval Research Laboratory in terms of man-hours consumed, military importance, and of results developed and applied to missile-guidance systems. Guidance equipment is being developed at NRL for three Navy guided missiles--the "Lark," the "Skylark," and the "Kingfisher E."

NRL has assumed responsibility for the development of a mid-course beam-rider missile-guidance system and of associated data-recording instrumentation, beacons, antennas, etc., for the Lark missile. This system will consist of an SP shipborne radar (and its mobile counterpart for field test use, the SP-1M) as modified for automatic tracking and missile guidance; and the NRL developed AN/APW-4 missile-borne beam-rider receiver. Effective engineering development of equipment of this type has necessitated investigation of many related problems (R-3090, Confidential). These principally include: Kinematics (R-3280, Confidential and R-3318, Confidential); spectrum analyses of frequencies contained in the trajectories of interest (R-2930, Confidential and R-3103, Confidential); servo-bandwidth requirements (R-3280, Confidential); guidance systems (R-3196, Confidential); propagation of electromagnetic waves through propellant gases (see section on "Propagation"); reflection, attenuation and modulation of the guidance-control line (R-3071, Confidential); dynamic stability (R-3070, Confidential); missile receivers (R-3318, Confidential and R-3144, Confidential); noise dispersion (R-3318, Confidential); airframe-response characteristics (R-3253, Confidential); autopilot and control response characteristics (R-3280, Confidential); and specifications for alternate and expanded control systems (R-3144, Confidential). In addition, procedures, techniques and instrumentation are being developed for guidance systems test and evaluation (R-3272, Unclassified and R-3303, Unclassified). Space does not permit a detailing of the origin, conduct, and findings of the above investigations. In general, the objectives of the NRL missile-control program have been determined by fleet requirements and by NRL plant and personnel facilities. Specific problems initially accepted were, for the most part, applied research and development problems. Their effective accomplishment has necessitated, (and has largely determined the topics of) a program of more fundamental studies and investigations in the control field. New knowledge thus generated is often rather widely applicable.

The extension and application of communications theory to the problem of controlled-flight dynamics has been found to be an extremely valuable tool. By comparison with conventional aerodynamic procedures this technique is often mathematically much simpler. In its applications it can be used for prediction of performance characteristics of a particular structural configuration, as well as for the syntheses of

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circuits and required configuration parameters. Signal-to-noise ratio, for instance, when applied to control dynamics, becomes a measure of the accuracy or precision of the system. The pass band required for the transmission of control intelligence with the desired system-response accuracy can be exactly determined by analyses of trajectory frequency spectra. It is thus possible to design control systems and elements to fit known quantitative performance requirements. This technique is applied by some other laboratories and is beginning to receive more general acceptance. Its extension and application at NRL has been quite profitable.

In July 1947, the first powered flight with completely automatic remote beam-rider guidance was accomplished. An SNB aircraft, equipped with a missile receiver coupled to the aircraft autopilot, automatically flew out a radar beam to a distance of 45 miles and at an elevation angle less than 3 degrees. The beam source was an NRL-modified SP search radar located at the Chesapeake Bay Annex. For a portion of the flight, the beam was displaced in both elevation and train to simulate tracking of a moving target. The aircraft automatically maintained a course following the moving beam. Subsequent measurements of system accuracy demonstrated performance as accurate as that of good free-space tracking with spot-scope-operated fire-control radar. At the close of the fiscal year research and development of the beam-rider guidance system for the Lark missile was approaching the crucial evaluation stage. Units of a production model of the AN/APW-4 receiver were being delivered and a modified SP-1M mobile radar designated Lark SP-1M had been completely modified at NRL for field evaluation of the Lark mid-course guidance system. During the next reporting period, automatic beam-rider guidance tests in Lark missiles will be conducted at NOTS, Inyokern and NAMTC, Pt. Mugu, Calif.

Considerable progress was made during the reporting period in the planning and preliminary design of a command-guidance system for the "Kingfisher E" and a passive homing system for the "Skylark" missile (R-3240, Confidential). "Kingfisher E" is a ship-launched guided missile equipped with an underwater homing torpedo. Skylark is the Lark missile equipped with command-mid-course and passive-homing guidance systems.

It was determined that a command-guidance system similar to that being developed by NRL under Project HORNET will be used for guidance of the "Kingfisher E." NRL has acted as consultant to a contractor who is producing in quantity the guidance-system X-band-receiver and beacon combination (AN/DPW-2) for Kingfisher. Several flight tests of prototype models of the system were completed. For these tests an SNB aircraft was continuously plotted in position using the NRL high-speed-lobing radar and a manual plotting board. The plane was guided in azimuth by the pilot acting on ground station commands which were indicated by left-right lights in the aircraft. The pilot, in response to these signals, successfully guided the aircraft to within 100 yards in azimuth of previously located targets. This work has been coordinated with other phases of the Kingfisher project, including data telemetering, an application of the NRL developed AN/AKT-1 system.

The Skylark project requires the development of preset-launching-guidance, command-mid-course-guidance, and passive-terminal-guidance systems for the XSAM-N-2 missile. The composite system is to be capable of guiding the Skylark from the point of launching to collision with an aircraft target. In this project, NRL has acted as consultant to the Pilotless Plane Division of the Fairchild Engine and Aircraft Co., prime contractor to BuAer for Skylark. NRL kinematics and systems

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studies indicated that constant-true-bearing guidance is realizable and is of the several courses considered, the closest approach to the ideal. The theoretical design of the control loop, of the radar-tracking loop and of a servo loop to reduce launching dispersion was developed. Desired autopilot characteristics were specified and the required modifications to the present autopilot were proposed (R-3280, Confidential). A breadboard version of the missile passive-homing receiver was constructed and demonstrated in record time by a team of NRL and Fairchild engineers working at NRL. Two months later the breadboard version was repackaged as a prototype model suitable for installation into the missile, and was successfully demonstrated. This rapid progress is in large measure attributable to the cooperative effort and close coordination of the Bureau of Aeronautics, the contractors and the Laboratory in the conduct of the project.

Another phase of this program, the development of an S-band beacon (AN/DPN-3) was completed during the reporting period. This beacon will be applied in the Lark, Skylark, and other missiles.

COUNTERMEASURES (R06)

The Radio Countermeasures Program is based upon a determination of the radio means, both offensive and defensive, which an enemy can employ. This determination involves an intelligence effort in the analysis of the technical progress of potential enemies.

Basically, the task of countering enemy radio-radar signals is twofold. First, the enemy signal must be intercepted and, if possible, its source located and its frequency determined; then the enemy's apparatus must be neutralized by active countermeasures such as jamming or creation of false-return signals. These basic needs of an effective countermeasure program have been the objectives of active research at NRL for many years. During the past year, the effort was directed toward the improvement of shore-based direction finders and their antennas, the development of equipment which will intercept and counter very brief transmissions, the consideration of new tubes and circuits, the study of radiation-reflecting materials, and other problems of a similar nature.

To meet the need of naval intercept services for highly sensitive shore-based direction finders, equipment is being devised and perfected to cover the frequency range of 30 to 140 megacycles. Besides high sensitivity and good bearing accuracy the system is to be capable of analyzing polarization characteristics of the arriving wave. Theoretical analysis has shown that the sensitivity of this equipment will be limited only by natural phenomena such as cosmic and solar noise. As a phase of this comprehensive investigation, mathematical analysis was made of the effect of the frequency characteristic or bandwidth of each circuit or component part of a direction-finder receiving system on the accuracy and sharpness of a visual bearing presented on a cathode-ray-tube type of bearing indicator (R-3182, Unclassified).

In directing countermeasures against extremely short enemy radio transmissions for missile guidance, detection, and communications, it is vital to have available instruments for immediate and reliable intercept and for interpretation of these signals. Equipment for this purpose is being devised with particular emphasis on operating effectiveness in the hands of electronic technicians who have a minimum of special training.

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The accuracy of intercept direction-finder systems may be improved by isolation of antenna arrays from the operating quarters of a station. It is also often desirable to control outlying stations of a direction finder net from a central point. These requirements dictate the need for remote control of direction finders. Systems for control of direction finders over wire and radio links have been devised and preliminary models of the former have been completed.

In order to determine the feasibility of extending the frequency range of an existing radio direction finder to cover the range of 5,000 to 12,000 Mc by the use of an available direction-finder antenna, the effectiveness of this antenna was evaluated against radar signals from planes at various altitudes and distances. This antenna was also evaluated to determine its beamwidth, its gain and its performance on signals of different polarizations (R-3149, Confidential). Another study of the properties of several types of antenna arrays was made in an effort to obtain improved high-frequency antennas for intercept and direction-finding purposes in shore installations. This study indicated the relative gain and sharpness of the main lobe of the directional pattern of the several arrays in both the horizontal and the vertical plane, as well as the ratio of the side lobes of a given array to the main lobe (R-3213, Confidential).

In order to improve the Model DAJ shore-based direction finder as a countermeasure device (by eliminating the possibility of failure to obtain a bearing on certain types of intercepted signals) it was desirable to have available to the operator a means of manual goniometer operation in addition to the fixed-speed motor-driven goniometer. This was provided for by the development and design of a modification kit which may be added to a DAJ to permit manual goniometer operation upon throwing a switch. The jamming of enemy signals to prevent the transfer of intelligence by radio propagation has proved one of the most effective of all countermeasures. All power-tube developments are therefore closely reviewed for possible application to this field. As these experimental tubes become available, measurements are made of their performance characteristics for jamming applications. Data are obtained on requirements for jamming systems, and techniques are developed and pertinent technical information furnished to the materiel bureaus for use in formulating equipment specifications, leading toward production contracts such as the AN/SLT-1 jamming system, on which the laboratory has served as consultant. An experimental X-band jammer, including the radio-frequency unit, modulation, power supply and antenna, was built around the A-131 magnetron tube. Measurements were made of its performance both in the laboratory and at CBA using the SU-2 radar.

A concurrent vulnerability study, directed particularly to the possibility of jamming, by electronic means, an X-band surface-search radar, disclosed that the power levels indicated for complete jamming would be excessively high (R-3282, Confidential).

In order to determine the type of modulation to be used against a specific transmission, a laboratory installation for effectiveness measurements has been maintained where different kinds of modulation can be compared with the simulated radar signal to determine their relative value for jamming. During the past year, the study of noise jamming of pulse signals has been continued and a versatile modulation generator was developed. This has variable output levels and noise bandwidths, producing noise of different characteristics for use in these studies. This noise source can also be used as a flexible modulator for transmitter work (R-3175, Confidential). Other units such as wide-band video amplifiers and analyzers have also been designed and built for use with the measurement analyses.

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In the actual operational use of countermeasures against high-speed enemy signals, the necessity for covering wide ranges of frequency in short time intervals makes manual control impractical. As an initial step in the development of automatic search and jam systems, a control unit was developed which tunes a receiver over a desired frequency range, stops it on a received pulse signal and automatically sets a jammer to the same frequency, and provides periodic monitoring of the victim signal during the jamming. This unit was combined with the AN/SPR-2 receiver and the AN/APT-10 transmitter in S-band, and the complete system was successfully flight tested against the SX radar at CBA (R-3119, Confidential). Work was also started on an improved system developed around the AN/APR-9 receiver covering 1,000 to 10,750 Mc and the AN/APT-16 transmitter covering 2,300 to 4,100 Mc. Other developmental or investigative work included: Antennas suitable for aircraft mounting and having characteristics for countermeasure application in S and X bands for use with the automatic system, more satisfactory means of look-through for the monitoring of victim signals during the jamming period (R-3173, Confidential), circuits for discriminating between pulse signals of different widths and repetition rates, and an auxiliary unit built for use as part of the automatic system.

In order to make possible the calibration of the DBM-1 direction finder over its entire frequency range, a series of pulse transmitters and associated antennas, covering a range of 90 to 5,000 Mc, has been developed and these units are now in production under Bureau of Ships contracts with the Laboratory serving as consultant.

Because submarines must be able to intercept radar signals in order to protect themselves from searching airplanes, the development of omnidirectional intercept antennas meeting the pressure and shock requirements of submarine service was undertaken. One antenna recently developed (R-3217, Confidential) covers a range of 1000 to 4000 Mc and is now in production under a Bureau of Ships contract.

The intercept receivers now available for use in the communication channels (15-Kc to 100-Mc) are not designed to provide the required versatility of operation and stability of performance. A new series of receivers for this service has been proposed to the Bureau of Ships. A group of NRL engineers has been serving in a consulting capacity to aid the Bureau in determining the physical, electrical, and operating characteristics for such a series of receivers.

Studies made during World War II of minimum detectable signals visible on radar ndicators demonstrated that very considerable improvements in effective signal sensitivity could be made by designing the radar system around optimum values of the system parameters. Similar studies of the indicators used with intercept receivers are now in progress. Work in this field to date definitely established the importance of controlling the intercept-system parameters within specified limits in order that the system will be able to detect and analyze effectively signals of low field intensity. Because of the complexity of intercept systems and the variety of indicators which can be employed, the study of minimum detectable signals will continue to be important to the future design of intercept systems. Through these studies the systems now used will be improved and new systems will be designed for greater effectiveness.

Comprehensive investigations on intercept of short bursts of signals or of random pulses have suggested new techniques which are being exploited in a new indicator which uses a five-gun cathode-ray tube with sweeps initiated by the first pulse received,

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permitting instantaneous presentation of pulse length and repetition rate regardless of "jitter" or random pulsing.

These short-duration signals are on the air so briefly that it is necessary to record them for subsequent analysis. Since conventional recording methods are inadequate, studies were made of various recording media with emphasis on the Haeff "Memory Tube" which promises to develop into an excellent tool for intercept recording

In the interests of improving the efficiency of reflecting material (countermeasures designed to confuse enemy radar) an extensive theoretical analysis was made to determine optimum distribution to produce the greatest return per unit of material. Results indicate the use of fine metallic fibers under ideal conditions will produce a much more efficient reflecting substance than has previously been produced. Methods for productions of these fibers were under development by the close of the year.

New designs of British and American balloon-borne reflectors, suitable for wind-finding purposes, have been investigated. The information thus obtained will form the basis of designs of radar decoys where tactical requirements can be met with balloon-borne reflectors.

SYSTEMS INTEGRATION (R07)

A primary function of naval electronic systems is to provide information for the rapid and accurate exercise of command. For maximum utilization of this information the several electronic systems must be combined into a coordinated and integrated whole. The attainment of effective integration involves both the determination of technological requirements for projected operations and the projected operations possible with advances in technology. In order that this bilateral advancement may be most rapid, there must be close alliance and collaboration between those versed in the operational and those versed in the technical. Thus necessary adjustments in operational and technological objectives to attain the desired goal with assurance of adequate exploration in both fields can be provided. A typical program approach, such as that outlined in the section on Navigation, describing the Carrier-All-Weather Flying Program, is considered to be the best long-term solution to this problem. Immediate fleet requirements, however, do not permit exclusive use of this detailed approach. The Laboratory is actively concerned with the problem of systems integration as related both to existing electronic systems and to those in a development stage. The systems-integration problem is particularly acute in aircraft where many electronic equipments are concentrated in a small area, and in shipborne combat information centers where a large quantity of information, much of which is received and partially processed by electronic means, is interpreted for fighter-direction and target-designation purposes.

A systems investigation of the P4M-1 control bomber was completed during the reporting period. The study revealed a number of unsatisfactory performance characteristics in the electronic system of that aircraft resulting from interference and interaction between components and recommended corrective measures (later worked out at NRL) to minimize interaction.

An airborne homing system (see p. 47) was devised in which the triggering of a home-ship beacon transpondor by numerous aircraft in flight is the basis for measuring at each aircraft the distance and direction of the home ship. It was anticipated

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that operationally as many as 300 different aircraft could be keying the beacon more or less simultaneously. A basic theoretical investigation of this "pulse density" problem resulted in the derivation of mathematical formulas which describe high-pulse-density conditions and which give the probabilities associated with the successful transmission and reception of pulse-type information under conditions of mutual interference from independent pulse sources. Developmental work on a pulse generator, capable of simulating the pulse output of 300 pulse equipments, was completed, and construction was in its final stages at the close of the fiscal year. This equipment will be used to check the theoretical results and to determine pulse-density limits for new equipment developments.

Studies are being conducted at NRL on methods and instrumentation for interference measurement, antennas for uhf measurement purposes, and methods of evaluating shielding effectiveness. Particular aspects of interference encountered in uhf communication systems have been analyzed and, where possible, remedial measures were indicated. Analyses of systems, employing crystal-controlled transmitters and receivers to determine the extent and pattern of within-band interferences, provided data on the relative interference-generating propensities of specific equipment designs and permitted pre-selection of interference-free channels for operational planning (R-3059, Confidential). Means were developed for improving the interference characteristics of Model-TDZ transmitters which could be applied to operating equipments in the form of field changes (R-3349, Restricted). Systems-integration investigations generated the need for special testing equipment. In this connection probe pickup devices for use in radio-interference testing were developed and calibrated. (During the reporting period the evaluation of electronic systems for all types of naval aircraft was transferred to a new group organized to conduct this work at NAS, Patuxent River, Md.)

A study is being made of two important aspects of the automatic aircraft-interception-control system. (This system is intended to provide a complete display of the current "air picture" in the neighborhood of a task force, permitting evaluation of the degree of threat offered by enemy targets and transmission of intercept orders to the selected intercept aircraft . The presentation will be given to the pilot in a form which will leave him free to effect his contact with the target by visual or electronic means.) The stated military requirements were expanded and clarified so that an estimate of the technical requirements of the system could be made (R-3342, Secret). A preliminary study was also made to determine the anticipated coverage characteristics of the several radars now under development for this application.

The desirability of televising important data between a CIC and the source of information or central evaluation location was the subject of another preliminary investigation. Some method of data transmission is essential to permit rapid decisions based on information from the large number of electronic systems aboard modern naval craft. The Haeff "Memory Tube" has also been evaluated for its possible applications to problems involved in the display of radar-relay information. Some anomalies have been noted in operation of experimental memory tubes, but it is expected that these difficulties will be eliminated in subsequent models.

Consulting services have been provided for the development of a virtual-PPI reflectoscope (R-3356, Restricted). This instrument was designed to permit matching the image of a chart directly on the radar display of the PPI.

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ELECTRON TUBES (R08)

Since the recent war, the Naval Research Laboratory has placed increased emphasis on research and development of tubes for many types of electronic applications and systems. A special group was established to do basic and applied research in this field. Last year this activity achieved notable success in the development of the A. V. Haeff "Memory Tube."

Research on cathodes has as its object the development of cathodes which are better than those now available, particularly for electron tubes operating at extremely high frequencies. A project on the determination of the electron-emission constants of thoria cathodes formed by cataphoresis was completed and the results published in a technical journal. Development of ceramic-type thoria cathodes made by pressing and sintering mixtures of thoria and metal powders was completed, and preliminary measurements of the thermionic emission and resistivity characteristics of such cathodes were carried out. A pulse method was devised for measuring secondary electron emission in the presence of primary emission from a cathode, and work was begun to correlate the primary and secondary emission properties of thoria cathodes with their performance in magnetrons.

The development of signal-storage tubes continued as one of the most important phases of the program. The object of this project is to develop multiple-playback electron storage tubes, applicable to radar, countermeasure, identification and computer systems, which are capable of any desired number of playbacks of yes-no information previously stored on a dielectric surface--the time necessary for storage, reading, and erasure being short compared with the time of a typical radar scan. The basis for this work is the important NRL invention known as the Memory Tube (Report of NRL Progress, June 1947, Confidential). The write-in, storage, and read-out characteristics of the Memory Tube have been further studied to determine optimum design. A special form of this tube, suitable for use in high-speed electronic computers, was devised for the Bureau of Standards and is now being further developed under a contract let by that agency. An "image-intensifier" Storage Tube, which permits direct viewing of the storage surface in daylight, was devised, built, and demonstrated.

Another important project was the work on high-power magnetrons. One of its principal aims was the determination of the limits of satisfactory operation of these high-power tubes, such as are required for long-range search radar. The tube studies required by this work have been made on scaled models. Experimental results on models of high-power-pulse magnetrons have confirmed the validity of basic magnetron design procedures. This information was made available to contractors engaged in development of such tubes for our long-range search radar equipment, and the problem was closed.

A fourth phase of the tube research involved microwave oscillators and amplifiers. Here the object of the project was the development of electron tubes which can be used as amplifiers and oscillators of at least moderate output power at millimeter wavelengths. No such tubes are currently available, and, as a result, systems development at millimeter wavelengths is seriously retarded. Considerable research on a modified form of magnetron, devised at NRL, and known as the Perturbation Grid Tube, yielded very little and consequently further work on this tube was discontinued. Late in the year an extremely promising and novel device, called the Electron Wave Tube,

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was invented and successfully demonstrated (R-3306, Unclassified). Further research and development work on this tube will be continued.

Electron tubes capable of switching the small amounts of r-f energy entering a radar receiver have been available for several years. A similar device, capable of switching r-f power of the order of 10 kw or more from one load to another in less than one microsecond, has been needed for IFF system apparatus. A triode gas tube for this purpose was devised, built and demonstrated. Switching ratios greater than 30 db, and insertion losses less than 1 db, have been realized with microwave equipments which utilized such tubes (R-3305, Confidential).

ANTENNAS (R09)

Some of the most stringent limitations imposed on the communication systems of the Navy stem from the difficulty of providing adequate radiating or collector systems, due to a chronic lack of suitable free space high in a ship's superstructure. This situation can be alleviated to some extent by reducing the number of antennas required without reducing the number of communication channels. Multicouplers and matching circuits have been devised by means of which as many as five transmitters (or receivers) in the uhf range can be accommodated simultaneously by a single antenna. Provision has been made for automatic dial-controlled tuning adjustments. Work is now in progress to provide similar operation in the h-f range.

A systematic study of sleeve antennas has been made, resulting in data which permit the determination of the physical dimensions of antennas from specific impedance and frequency range requirements, or conversely, for determining the electrical characteristics of a given physical design (R-3354, Restricted). This has permitted antenna designs to be evolved wherein portions of a vessel's superstructure, such as stacks, have been incorporated into the radiating system. A shielding obstacle is thus transformed into a useful radiator with consequent improvement of the radiation pattern. An automatic-matching system, to assure presentation of the correct terminating impedance at the base of a standard high-frequency antenna, has been developed. When the frequency of transmission is changed, or when natural or accidental effects influence the antenna characteristics, the antenna will automatically be matched to the new condition. The development of satisfactory components and refinement of controls requires further study.

Present shipboard communication systems attempt to employ antennas which have, as nearly as possible, an omnidirectional pattern in the horizontal plane. This permits contact with other craft in any direction. In and above the uhf region, however, beamed transmission by means of directional antennas is desirable in order to achieve increased security and reliability. To utilize such directivity in a mobile system, antennas at the terminal points of the circuit must remain aligned regardless of changes in the relative position of the terminal stations. Consequently, a primary objective of the program is the development of a suitable antenna control system. Several possibilities have been explored and those showing greatest promise are being rigorously analyzed. Antenna control can be applied to shipboard relay transmission, so a cognate study was undertaken to prepare data on relay-transmission methods.

Another major effort in this work is the development of a background for the design of rapid-scanning antennas (R-3184, Unclassified), a subject in which satisfactory designs were not achieved during the war. This effort is being concentrated on the optical-scanning principle which requires a wide field of view, a focusing objective

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and a rapidly scanning eyepiece—the antenna feed (R-3312, Unclassified). A method of focusing which utilizes Fresnel's concept of half-wave zones was investigated as a possible means of simplifying construction or improving performance. It was found that one-medium designs yielded results comparable with paraboloid reflectors for off-axis performance, but inferior in gain by at least 3 db. The Fresnel zone-plane work has been terminated with a report (R-3293, Unclassified). A figure-of-revolution antenna design suitable for rapid scanning over a 90° sector was devised. This antenna consists of a circular toroidal-bend reflector, a metal-plate constrained-wave correcting lens having axial symmetry, and a rotating feed horn. A scheme devised by the Bell Telephone Laboratories, which uses light dielectrics loaded with conducting particles for large microwave antenna lenses, was studied theoretically and experimentally.

Because of their applicability as very-low-drag devices on high-speed aircraft and missiles, dielectric antennas received fundamental study. The object of this study is to determine optimum design procedures for such antennas, both in free space and in close proximity to metal structures. Interim design techniques and an analytical technique for further basic study were established.

Current need for compact wide-band antennas which permit reception of signals of any polarization over a hemisphere, and the unsatisfactory results obtained with conventional antennas, prompted a theoretical and experimental study of helical radiators. Both single- and multiple-wound helixes were developed. It was established that a single helix can be designed for endfire with circular polarization on axis, or for principal maxima on an arbitrarily chosen cone with near circular polarization on that cone (R-3357, Unclassified). A multiple helix can also be designed for broadside-type patterns with a variety of lobe structures possessing near-circular polarization everywhere.

In a study of the direct conversion of r-f radiation into visible radiation, various mechanisms for such direct conversion were considered, and the effect was experimentally demonstrated by means of a temperature-sensitive phosphor on an absorbing screen. The project was terminated with a report (R-3204, Unclassified).

Several antennas were developed for missile beacon-and-guidance systems. An omnidirectional antenna, consisting of a single three-dipole element in a streamlined housing, was designed to operate at two frequencies and thereby serve two beacon systems on the KUW-1 missile. For the AN/APW-4 guidance system on the Convair "Lark" missile, a two-dipole linear-array antenna was mounted in dielectric section of the vertical aileron. For the same system on the Fairchild "Lark" missile, two dielectric endfire antennas were developed at different frequencies.

In the list of completed developments was an antenna for use with the airborne bombing-radar, AN/APB-2. It consists of a shaped double-curvature reflector illuminated by a movable horn feed. This antenna possesses the unique design feature that the radiation pattern can be adjusted to the altitude, so that uniform ground illumination is obtained (R-3224, Confidential).

The essential characteristics of directional-null-type antenna pattern, produced by superposing two primary antenna patterns phased by 180°, were studied theoretically and experimentally for purposes of determining design parameters and estimating effects of departures from optimum. Reports describing this study were prepared (R-3162, Unclassified, R-3245, Unclassified, R-3279, Secret).

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The increasing vulnerability of submarines to radar-equipped ships and aircraft has created an urgent need for countermeasure direction finders covering all frequencies likely to be employed for radar. In partial solution of this problem a direction finder is being developed (R-3115, Confidential) for submarines to cover the frequency range 2,500 to 10,500 Mc. It is to be integrated into the AN/SPR-4 intercept system and will provide visual indication of the bearings of the intercepted signals.

CIRCUITS, COMPONENTS, AND INSTRUMENTATION (R10)

The improvement of existing electronic equipment and the creation of new equipment requires continuous research in the fields of electronic circuits and components. Investigations at NRL in this field are conducted in support of the Laboratory program as well as to fill specific needs of the Navy where available instruments and techniques do not suffice.

During the reporting period, work was completed on equipment designed for the field calibration and test of vhf communications equipment (R-3242, Confidential). A theoretical analysis and successful experimental demonstration was made of the new transformerless-type bridge-stabilized oscillator (R-3082, Unclassified). The initial planning for a novel frequency meter, utilizing an oscillator of this type, was completed and work continued to determine the practicability of special circuitry which will eliminate harmonic-number uncertainty. A stable high-frequency oscillator, operating on 28 volts through the frequency range 475 to 525 Mc, has been completed. Frequency-stability studies on the final design of this equipment are now in process. Self-starting resonant-type frequency dividers have been developed. Also, a novel treatment of frequency multiplication, theoretical and experimental, has been applied to single-tube harmonic generator design (R-3166 Unclassified and R-3309, Unclassified).

The Laboratory, during the reporting period, designed a functionally ideal electronics-standards laboratory and has developed several prototype equipments necessary for its operation. NRL has also acted as consultant to the several naval bureaus and bureau contractors on design and development of production equipment patterned after the prototype. A plan was formulated to follow this program by developing precision power-measuring facilities suitable for the electronics-standards laboratory. Also, some work in microwave spectroscopy has been planned to ascertain the suitability of a gas line as a frequency standard.

To make possible research and development on radar and communication systems at millimeter wavelengths, an extensive development of r-f components for these wavelengths was undertaken (R-3223, Unclassified). Working models or drawings are now available for a large variety of components needed for work in the 5 to 9-mm wavelength range. These include antenna horns, taper sections, high-power dry loads, "tees," "magic tees," double-stub tuners, E and H bends, Army-Navy standardized millimeter waveguides, wavemeters, long-slot directional couplers, variable attenuators, and standing-wave indicators.

To meet existing needs at NRL and at other Navy activities, a comprehensive program was undertaken to devise and develop antenna-measuring apparatus and instruments. A 550-foot range for measuring directive-antenna patterns at K-, X- and S-band, an automatic recorder for directive-antenna patterns, and two remote-controlled primary-pattern equipments have been designed, built and installed. An

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electromechanical-pattern computer was designed and built. This computer samples phase and amplitude at 45 points across an aperture and computes from this data the radiation intensity of the diffraction pattern as a function of angle. Other developments included an automatic phase-front plotter of the Iams type. An automatic recording scheme for antenna patterns was devised on the basis of no mechanical acceleration. It has been found to provide a rise rate of 400 inches per second at critical damping.

A method was invented for the direct, rapid and simultaneous measurement of the complex components of a two-terminal (or transfer) admittance or impedance. Satisfactory apparatus which utilizes this method for the measurement of the real and imaginary parts of admittance over a frequency range of a few kilocycles to several megacycles was built and demonstrated. This method appears, on paper, to be workable over large bandwidths and up to the very highest frequencies.

Studies were conducted to determine the optimum possible amplification over a uhf band with the best tube types available. Work was done on three aspects of the general problem of miniaturization, namely, circuit simplification, the elimination of generated heat, and operation of equipment at high powerline frequencies: 225 to 400-Mc preselector circuitry was developed capable of providing performance greatly superior to that of the present Model-RDZ preselectors. A study of anti-jam circuitry was undertaken, with the initial purpose of analysis and integration of this complicated field, and studies were continued on amplitude-selective circuitry in the limiter category.

In the general field of optimum utilization of antenna collected energy, theoretical and experimental studies were made of underwater vlf antenna-coupling networks which have general applicability at other frequencies. Several primarily consultative projects were handled, such as the application of f-m ratio-detectors to frequency-shift reception.

Work in the field of series-resonant crystal-oscillator circuitry resulted in extension of the operating range to over 100 Mc, and studies of crystal-overmode operation and the relations between overmode frequencies were continued. Investigation of crystal temperature-frequency hysteresis effects resulted in recommended changes of crystal mounting design, which made available a type of crystal needed in many applications.

A project for improving powdered-iron material intended for radio-frequency use was carried on with the services of an outside consultant. A new type of radio-frequency conductance-measuring device, capable of very accurate measurements up to 100 Mc, was developed. A unique means for measuring minute capacitance increments (on the order of 0.001 micromicrofarad) was also developed as part of a study of the temperature coefficient of dielectric materials. The first broad-band signal generator known to have been produced covering the frequency range of 3600 to 7500 Mc was developed and a working model fabricated. After a study of the field of precision-frequency-measurement up to 30,000 Mc, new techniques have been developed which at present extend the utilization of the Model-LAM primary frequency-standard to 400 Mc (Instruction Book for Model LAM Precision Frequency Calibrating Equipment, Unclassified).

A decade crystal-generator employing frequency drift cancellation has been under development, in cooperation with an outside contractor. This system is inherently capable of providing relatively simple means for setting, controlling and maintaining

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frequency with precision approaching that of the best available frequency standards. A technique and instrument were developed to facilitate the measurement of microwave power at levels as low as 0.1 microwatt. This system incorporates bolometric methods and utilizes the mechanical resonance of the indicating galvonometer by switching from the radio to the audio power at the proper rate to give maximum sensitivity for bridge balance, giving precise results without painstaking attention to temperature regulation.

The causes of frequency dispersions exhibited by invar cavity resonators were investigated. "Stable Invar" was found to possess an expansitivity anomaly of 8.7 x 10^{-6} in/in/$^{\circ}$C of temperature cycle. All known metals revealed anomalies which make them unsatisfactory for the construction of highly accurate resonators. In the investigation of nonmetallic materials it was found that fused quartz, while exhibiting anomalous characteristics, has an anomaly several orders smaller than that of metals. It could be predicted that fused-quartz resonators would show an improvement of approximately 280 times in this respect. The fused-quartz resonators are approximately half the size of equivalent air-dielectric-cavity resonators but have a lower Q (R-3155, Confidential). These studies required an accurate and convenient means for making X-band frequency measurements. A system that fulfilled these requirements and has more general applications was developed (R-3283, Restricted). In the general field of frequency control and stabilization a standardized crystal oscillator in the range 2 to 6 megacycles was required. Efforts in this connection resulted in the development of a circuit, which, under the combined effects of extreme temperature variation, supply, and cathode heater voltage variation, stabilization, tube change and change in loading, demonstrated a stability of 0.0012 percent or better. This permits a crystal unit tolerance of 0.0013 percent, if a 0.0025 percent overall tolerance is to be attained, (R-3198, Confidential).

PROPAGATION (R11)

The propagation of radio waves has been one of the Naval Research Laboratory's chief basic research programs for more than twenty-five years. Of the many phenomena to be considered under this complex subject, major emphasis has been placed on the following during the past fiscal year: A continued development of materials that will absorb radio waves; measurement of the "radar area" of certain targets, particularly guided missiles; a study of the scattering of radio waves caused by the sea and by raindrops; an analysis of the radiation from the sun in the micro-wave region; measurement of the surface reflection of energy radiated at low elevation angles, and a study of the attenuation of radio waves by the gas and flames emitted by a jet-propelled missile.

The object of the work on absorbent materials is to develop materials which will absorb radio waves, and to develop applications of such materials to countermeasures, antenna systems, instrumentation aids, etc. Materials have now been developed which absorb 95 percent or more of the incident energy over bandwidths of 25 to 30 percent throughout a frequency range of 200 to 10,000 Mc. Similar material has been developed which absorbs 95 percent or more of the incident energy over bandwidths of 15 percent at a frequency of 25,000 Mc. This decrease of bandwidth comes about because the real part of the permeability for all magnetic materials studied, either pure metals, alloys, or oxides, decreases to unity at this high frequency. Special materials were made to absorb radiation for angles of incidence near grazing. Materials were made for X-band, which absorb well for angles of incidence only 10° from grazing incidence. Several successful aircraft and ship applications of absorbent materials were developed.

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Data on the "radar area" of missiles are needed in order to determine the detection ranges of such missiles by search radar. Mobile radar equipment was developed with which quantitative measurements can be made, and measurements were made at 100 Mc and later on 1200 and 3000 Mc. The equipment was set up at White Sands Proving Ground and used to obtain radar-area data during several V-2 flights. At 109 Mc the V-2 missile has a peak radar area of 150 square meters and shows fluctuations of 3 db before fuel cut-off; this figure might be reduced to 25-65 sq.m. if more precise data were available on the component of ground-reflected energy. After fuel cut-off, the peak radar area varies between 0.3 and 3.0 sq. m. and fluctuates more than 10 db (R-3220, Restricted).

On 1250 Mc, the radar area was usually of the order of 1 sq.m. except for regular peaks (usually between 40 and 100 sq. m.) that occurred when the rocket was tumbling. On 2825 Mc, peak values between 1 and 3 sq. m. were measured during a portion of the flight before fuel cut-off. Just after fuel cut-off, values between 10-300 sq.m. were measured. The general level during tumbling was below minimum detectable signal (about 40 sq.m.) and most of the peaks during tumbling were between 2,000 and 10,000 sq.m. A portion of the record just before and just after fuel cut-off indicates that the echo was extended in range during this period.

A Laboratory development of a model range for the measurement of radar area of missiles and aircraft by means of models was completed and the equipment installed at its field location. Various difficulties incidental to field operation were encountered but these have been, or will be, eliminated.

It is expected that quantitative knowledge of the scattering of radio waves from the sea would be of considerable help in developing airborne radars for the detection of small targets, such as schnorkel, in a sea. For this purpose,--and also to study the scattering of radio waves from rain clouds, which may be of value to meterorology,--suitable equipment was developed and installed in a PBM flying laboratory. This equipment consisted of radars operating at 1200, 3300, and 9500 Mc; a simulator unit which injects into the radar receiver a signal of controllable output, range, and effective antenna beamwidth, used to determine the minimum detectable PPI signal in the presence of sea clutter as a function of various radar parameters; and an aircraft disdrometer (see "Meteorology" in the section on Physics), which measures rain-drop size distribution, and so permits correlation of radar scattering measurements from rain and drop size. Measurements were made with this equipment during an expedition to Panama in December, 1947. These measurements were not in agreement with existing theory of rain clouds as radar targets, and suggest that the theory must be revised.

Sea-clutter measurements at 3,000 and 9,500 Mc were made in the vicinity of Panama during December, 1947. These measurements were made with the radars under independent control and were restricted to horizontal polarization. The results, together with previous data collected by other agencies, were used to assist in arriving at recommendations for a new anti-schnorkel radar.

A study of the intensity of radiation from the sun in the r-f spectrum is of interest because of its possible bearing on radio propagation and its contribution to a more thorough knowledge of the nature of the sun. Measurements have shown that the intensity of radiation at 10,000 Mc is greater than would be predicted on the assumption that the sun radiated as a black body, and that it is a function of sunspot activity. An X-band radiometer using an 8-ft parabolic antenna was built and installed on a destroyer escort and used to measure the intensity of solar radiation at 10,000 Mc during the

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total eclipse which occurred on May 20, 1947. Analysis of the data showed that a total optical eclipse does not result in a total microwave eclipse, that an appreciable fraction of the received energy comes from sunspots present, and that a small fraction of the received energy comes from the corona. The data was also used to obtain a function for the distribution of radiation across the sun; this distribution function is at considerable variance from that predicted by current theory.

Daily readings on the sun, sky, and moon have been taken, when possible, in an attempt to correlate effective temperature and sunspot area. During the course of these measurements it was noted that the presence of wet snow on the parabolic reflector of the antenna introduced a spurious reading which increased the apparent sky temperature by 200° C. This was due to thermal radiation of the snow, which is much higher in temperature than the free space at which the antenna was pointed.

To extend this work to millimeter wavelengths, an accurately machined 10-ft paraboloidal reflector, built by Norfolk Naval Yard, was mounted on an equatorial mount and arranged so that it could be remotely controlled and made to follow the sun or a region of the sky in the same manner as an astronomical telescope.

One of the most difficult problems encountered in the transmission of missile-guidance intelligence by radio is created by surface reflection of energy radiated at low elevation angles. A long range study has therefore been undertaken with the object of gaining as much information as possible about low-angle radio propagation. The findings of this investigation should be applicable to improvement of low-angle radar tracking as well as to the design of simpler and more compact missile-guidance receivers.

The beam-rider control receiver can not distinguish between a false crossover and the main crossover of the radar beam itself. Studies have indicated that the existence of multiple control paths at low elevation angles can compromise the tactical usefulness of the beam-rider as a guidance system. A successful system must be so designed as to minimize false-control-line effects. Initial studies of this problem have resulted in important receiver modifications, and in the substitution of vertical for horizontal polarization. A long-range series of correlating flight tests has been undertaken to determine the existence, the sense, magnitude and effect of false-control lines caused by surface reflections and radar side lobes.

A basic study of the quasi-optical effect of propellant gases upon electromagnetic propagation has been underway at NRL for several years. All guided missiles now under development will be jet-propelled and will thus interpose, between the remote guidance station and the missile, a mass of hot ionized gas. The nature and extent of adverse propagation and incidental modulation resulting from this flame is of important interest in the development of missile-guidance systems. (R-3108, Confidential and R-3197, Confidential).

Measurements of flame attenuation and incidental modulation have been made on the ground using the Lark acid-aniline motor, to determine the nature and extent of jet-flame interference with the propagation of the S-band electromagnetic waves. In these ground tests, it was observed that there was more of a redistribution of S-band electromagnetic waves. In these tests it was also observed that there was more of a redistribution of S-band radiated energy than there was attenuation. The flame did not produce significant incidental tone modulation of the signal. The ground tests can be considered valid only for the specific combination of motors, fuel, and signal frequency examined. Its findings should not necessarily be extrapolated as the basis for

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conclusions regarding flame effects during missile flight, or for other fuel, motor, and frequency combinations (R-3209, Confidential and R-3261, Confidential). Isolation and analysis of certain of the factors that may contribute to adverse-propagation and incidental-modulation effects have been undertaken.

A study is also being made of radiant-energy absorption by various molecular structures. Techniques have been developed for the determination of temperature and ionization distribution in a rocket-type flame. Considerable progress has been made in the construction and acquisition of optical and electronic test equipment required for the application of these techniques in tests scheduled to be conducted by NRL next fall. These trials will be concerned with attenuation at S-, X-, and K-band, as a function of contamination by low-ionization-potential salts. Simultaneously, temperature and spectrum determinations will be made. In-flame propagation measurements and flame reactions on the impedance of an in-flame probe are to be attempted at X- and K-band frequencies. Temperature distribution in gray body and line-spectrum type flames are also to be determined by an analysis of photographed data to be taken.

An investigation of vertical and horizontal polarization of S-band frequencies propagated through an acid-aniline flame has been completed and will be reported during the next reporting period.

PRECISION LOCATION (R12)

Work under this program has included investigations of radar systems and components applied to the acquisition and precision tracking of targets and missiles, and for the obtaining of the extreme target resolution, through the development of sequential- and simultaneous-lobing radar systems (R-3221, Confidential). Radio-frequency electronic-switching devices at high-power levels are being investigated and high-resolution radar techniques studied. The program is also concerned with the determination of operational requirements for various precision-location systems.

The high-speed-lobing (HSL) and simultaneous-lobe-comparison (TAB) radar techniques, which originated at NRL (R-3116, Confidential), were demonstrated during the last reporting period. Since their demonstration as operable systems, progress has been made in refinement, evaluation and in supporting research studies (R-3268, Confidential). Performance analyses of both the HSL and TAB radar systems have indicated that errors contributed by the antenna mounts, and errors due to the finite size of the targets, are very much greater than the errors inherent in the electronic systems themselves. For these reasons attempted comparative measurements of the tracking performance of the systems has not proved conclusively the superiority in tracking of either system. Experimental investigation, using an off-frequency beacon as a point source compared to an airplane target, are under way to study the effect on the precision of tracking due to the finite size of the airplane. Improved mounts have been planned for the commercially produced HSL and TAB systems now under construction. This construction, under Bureau of Ordnance contracts, is progressing with the Laboratory acting as consultant to the manufacturers.

Performance tests of the HSL System have indicated its tracking capability to be as good or better than any automatic tracking radar known to the Laboratory with the exception of the experimental Radar Mk 7, whose slightly better performance can be attributed to a considerably better antenna mount. Work is progressing at a commercial institution on the development of broadband switch tubes for the HSL system, and on the development of high-power switch tubes capable of handling up to 100 kilowatts.

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Complete automatic operation of the TAB system and all three coordinates was accomplished in July 1947. Preliminary tests made to date indicate very smooth tracking capabilities. Application of TAB radar to target acquisition, precision angle-of-arrival measurement, and of missile guidance, is being actively investigated. During the reporting period a greatly simplified method has been devised for comparing on paper, the characteristics of multi-horn-feed antennas--these may be arranged in a multiplicity of ways for application to tracking radars.

A basic study of high-resolution-radar phenomena has been undertaken by the Naval Research Laboratory. This investigation will include the design of a radar having much greater range resolution than the best contemporary systems, and will require devising new and unique electronic components for short-pulse generation and indication.

These techniques lend themselves to the detection and discrimination of small targets. The detection by radar of a schnorkelling submarine and of aircraft maneuvering in thunderstorm areas illustrate important applications of high-resolution radar equipment. In connection with this study, several equipments have been completed during the reporting period. One of these is a modulator capable of producing pulses of 0.01 microseconds, together with test equipment suitable for measuring and viewing these pulses.

APPLIED PSYCHOLOGY (R13)

Work at the Naval Research Laboratory in this field is principally concerned with the behavior of a human being when used as a link in a mechanical-control situation. Research is being conducted applying conditions similar to those encountered in operational tracking of targets. The results should yield basic information, regarding human response characteristics, that may be applied to such problems as conventional target tracking, the acquisition of guided-missile targets, and the piloting of supersonic aircraft. Considerable data have been taken using operational equipment which describes human response to simulated tracking stimulae. Comparative human response to visual and auditory signals has been measured, using several types of reaction modifying and measuring equipment (R-3248, Unclassified).

During the reporting period, the devising of improved experimental equipment (R-3297, Unclassified) has resulted in tests with particularly interesting results. Previous work had suggested that when a human responds to a visually presented square-wave error, the response, once started, runs off without visual feedback control. Tentative proof of this hypothesis has now been obtained. Preliminary experiments have been run where the visual feedback has been eliminated during the course of a response by (a) turning off the signal an instant before the response starts, and (b) disrupting manual control of the signal so that no matter what the subject does, the error to which he is responding remains unchanged. In both of these special conditions, the subject behaves in no demonstratively different way than he did when visual feedback was present (R-3249, Unclassified). Apparatus is now available and plans have been made to probe the characteristics of the human time constant under conditions of rapid, successive responses.

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SOUND

TRANSDUCERS (S01)

This program has to do with generation and reception of acoustic energy, principally under water. The research for the present year covers work on a crystal transducer, on a crystal standard hydrophone, and on certain aspects of magnetostriction transducer development.

Crystal Transducer Research. — Included in the NRL Transducer Research program was the development of a double-face ADP crystal transducer designed for use with the helicopter sonar. The operating frequency was 28-34 kc. The bandwidth was greater and the low frequency response was better than a competitive model which was, however, lighter and could handle greater electrical power. Certain theoretical calculations on the behavior of a hypothetical acoustic source which was divided into concentric zones were made. The zones in the source were driven at the same phase but the amplitudes differed. Beamwidth, height, and angle of the first three secondary lobes, and array efficiency, were computed for two 2-zone sources, one where the inner zone was driven at twice the amplitude of the outer, the second where the amplitude ratio was 3 to 1.

The construction and calibration of a standard hydrophone similar to the NRL OLA unit was also accomplished. The new unit used lithium sulfate crystal plates instead of the tourmaline crystals characteristic of the OLA units. The tests show that the new standard is 17 db more sensitive over the frequency range 5-100 kc than the OLA. The internal impedances were nearly the same for both units.

Magnetrostriction Transducer Research. — In September, 1947, the static and dynamic magneto-mechanical properties were determined of a sample of an aluminum iron alloy called ALFER, developed by the Japanese for use as a magnetostrictive material. The data are presented in such a manner that each property can be compared numerically with the corresponding one reported for "A" nickel in Harvard Underwater Sound Laboratory (HUSL) Report No. 3248. The Alfer alloy is of interest because it does not contain the strategic material nickel.

Progress in the instrumentation and enlistment of the aid of other laboratories in the prosecution of the program of study of magnetic and magnetostrictive materials also was accomplished. An electric furnace for heat treatment of samples in controlled atmospheres was installed. A direct reading Western Electric impedance bridge, a source of bridge power very accurate as to frequency, and a high-gain high-selectivity tunable detector and equipment for precise control of polarizing current were assembled. Arrangements were made for the cooperation of one of the Bell Telephone Laboratories' scientists, an expert on ferro-magnetism.

In July, 1947, NRL reported a contribution to the Bureau of Ships torpedo countermeasures program. This was a crystal projector which emitted 55-95 kc underwater sound in all directions and the required output of 90 db vs 1 dyne per cm^2 at one meter was realized between 65 and 90 kc when the projector was driven by a 750-watt power source having an interval impedance of 25 ohms resistive.

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Another transducer was developed for use in the torpedo countermeasures program. This transducer has a large sound collecting area, a low threshold of response and is nondirectional in the horizontal plane. Even at the high frequency end of its range (3 kc to 120 kc) the beam in the vertical plane is broad. The transducer is assembled of 45-degree Z-cut ADP crystal plates.

In the field of exploratory research a study of "transductors" was made. The transductor is a magnetic amplifier. It is sturdy, stable, and has many uses. NRL purchased two which had been imported from Sweden. One possesses two pairs of control windings and will produce a power amplification of 600; the other is a device for closing a relay by means of the change in current from a photo-cell. The latter transductor has four windings: 1) the main a-c winding, 2) the feedback winding for increasing sensitivity, 3) a biasing winding to shift the operating point, and 4) the control winding. Detailed data on the magnetic and electrical properties of both transductors were assembled.

PROPAGATION (S02)

It is very important for success in the development of good sonar equipment that a thorough understanding of the physical processes of sound propagation, especially in liquids, is built up. The study of sound propagation at NRL is divided into two fields. One has to do with sound propagation in the ocean, the other with the sound phenomena in samples of academic size in the Laboratory.

Ocean Sound Propagation. — In August, 1947, data were assembled on measurements of sound velocity in the neve of the Ross ice shelf. Neve is the tightly-packed snow found on high mountains and around the earth's poles. It was possible to saw bars of neve out of the Ross ice shelf at various depths. The sound velocity using the ultrasonic pulse technique was found to be 2,300 ft/sec in the horizontal plane and 4,600 ft/sec vertically. The measurements were made by an NRL observer who accompanied the Navy's 1946-47 Antarctic Expedition.

Sound Propagation. — The laboratory measurements reported during this reporting year had to do with two classes of media--one, liquids and molecular dispersions; the other, suspensions of particles in liquids.

In July, 1947, measurements were made of the sound velocity in a series of silicone fluids. The velocity was found to be low compared with other liquids.

In an attempt to clarify the mechanism by which ultrasonic irradiation causes chemical reactions, the process whereby iodine is produced in aqueous solution of potassium iodide containing some carbontetrachloride was studied. It was suggested that the reaction in the sound field took place between water and the dissolved carbontetrachloride and that the reaction was caused by the large mechanical and electrical forces generated at the collapse of the cavitation bubbles. The potassium iodide is primarily an indicator of the amount of oxidizing chlorine produced.

The velocity of sound in a pure liquid depends on the chemical structure of the molecules. A study of this dependence was made. The velocity of sound in twenty cyclic compounds was measured at an ultrasonic frequency of 3 megacycles. The measured velocities were found to lie between 1100 and 1550 meters per second ±0.03 percent. The molar sound velocity $R = v^{1/3}M/d$ was used as an aid to correlation of results (v is velocity of sound, M is the molecular weight, and d is the density).

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R for the molecule may be calculated from the fact that it is the summation of the R increments for the separate chemical bonds. The velocity of sound in a pure liquid may therefore be computed from a knowledge of the molecular structure. A further study of the relation between sound velocity and molecular structure was also made. The velocities in ten liquid halides were measured. The velocities ranged from 750 to 1,000 meters per second.

Extensive research was conducted on propagation of sound in discontinuous media, namely, in liquid suspensions and emulsions; reports were rendered in August, September, November, and December, 1947, and in January, 1948. Measurements of the absorption of ultrasound at frequencies between 1 and 15 megacycles in suspensions having particle sizes above 2 microns diameter indicate that the absorption is proportional to the area of particles per unit volume of suspension. This indicates that surface friction plays a part in absorption. The absorption is less than this when the particles are less than 2 microns in diameter. By using liquids of different viscosity it was found that the increment of absorption produced by introduction of the suspended material was the same regardless of the viscosity of the liquid. Stokes' theory was used in computing the variation of absorption with particle size and with viscosity of the suspending liquid. The theory seems to be applicable to the irregularly shaped particles of kaolin and sand used in the experiments in spite of the fact that Stokes' expression was derived for rigid spherical particles. Agreement within about 30 percent was found between theory and experiment in the frequency range 1 to 15 megacycles. Suspension of fine sand (particle size ranging from 2 to 45 microns) at a concentration ranging up to 30 percent exhibit a velocity of sound at one megacycle which differed considerably from what was expected if the sand suspensions behaved like homogeneous mixtures. The velocity was within 3 percent of the velocity of water alone.

LOCATION OF SMALL OBJECTS (S04)

The location of small underwater objects such as beach obstructions and especially mines is an important naval problem. Sonar techniques alone are practical for useful ranges. But here the resolving power depends upon the ratio of the sonar pulse length to the extent of the target in depth. The smaller the target and the closer they are spaced the shorter the sonar pulse must be. The importance of the problem led to the establishment of the Short Pulse Sonar program. An important instrumentality in this program is the fixed sonar installation (QBH Herald Type) mounted on the bottom of the Chesapeake Bay at Fort Monroe, Virginia. With this equipment, modified for short-pulse echo-ranging, many problems connected with location and detection of small craft and mines are being worked out.

RECORDING AND REPRODUCTION (S05)

This program has to do with recording and reproduction of acoustical phenomena. The recording means may be any device well proved in the art: namely, disc, magnetic tape or wire, and plastic film. The aim of the program is to have the proper equipment and skilled personnel available to record and "play back" in a quantitative manner acoustic phenomena which are observed in connection with sonar research. Ordinarily the events of interest pass so rapidly that meter reading and manual recording are out of the question. Also, restrictions imposed by working conditions in the field often demand automatic recording. With adequate fidelity and proper calibration of equipment, the records may be analyzed in the Laboratory at leisure and under conditions favorable to accuracy.

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A study of the response-frequency characteristics of one German and a number of American recording tapes indicated that 1,000 separate pulses per inch of tape could be recorded. The tapes and wires in the possession of the Laboratory have been sent to the Franklin Institute to have their magnetic (B-H) curves determined.

A group of captured German microphones, headphones, and throat microphones ("Laryngaphones") assigned CEE No. 18302, were submitted to the Laboratory, for evaluation, by the Bureau of Ships. Three types of headphones were tested--two magnetic and one dynamic, all having a resonant acoustic output. The dynamic headphone, although having a good physical appearance, would not stand up under humidity, shock, and salt spray tests. The magnetic phones withstood the test much better but both showed definite points of failure. Carbon and dynamic microphones were also tested. These also failed the tests. Neither the German headphones nor the microphones proved to be superior to existing Navy types.

SONAR ELECTRONICS (S06)

Noise is the phenomenon which puts a limit on the effectiveness of sonar equipment in the detection of echoes or target sounds. The noise may originate in turbulence and cavitation in the water or may originate in the electrical circuit components which make up the sonar receiver. Regardless of its origin, the noise ultimately appears as a complicated voltage which tends to obscure the desired signal at the indicating end of the system. A study is being conducted of the effects of complicated electrical voltages with a view to reducing or eliminating the disturbing effects of noise. A frequency translator was developed for performing narrow-band analysis of signals up to 23 kilocycles; the translator is linear to 1/2 db over a range of 60 db or more at any setting of the attenuator, and therefore makes possible the automatic recording of noise spectra.

SONAR SYSTEMS (S07)

The maximum submerged speed of known submarines, prior to World War II, was about 7 knots. Their normal maximum operating depth was about 300 feet. The antisubmarine sonar technique of detection, holding contact, and attack was a relatively slowly developing problem in plane geometry. As soon as it was revealed that the Germans were forced to depart from the idea of a submersible surface ship and build a true submarine capable of deep submergence (1,000 feet) and high speed (17 knots), the antisubmarine warfare people realized that the sonar problem had become a three-dimensional problem which developed much too rapidly for the old semimanual operations. Through its Sonar Systems research program, NRL made its contribution to the attack phase in the solution of this difficult problem.

Once the enemy submarine has been detected by sonar, it is of paramount importance that contact be not lost at any time in spite of the high speed, great depth of operation and maneuverability of the modern target. In addition, the target position in three dimensions (slant-range, bearing, depth) must be determined and relayed to the ordnance attack team.

The three-dimensional, rapidly developing problem demands improvement in the sonar system in the following respects:

a) Improved accuracy in the control of direction of the sonar beam
b) Display and recording of smooth sonar data (depth, range, bearing, or their geometric equivalents)

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c) Reduction of interfering noise

In the systems under study at the Laboratory, improved accuracy of sonar-beam direction control is obtained through the use of: 1) gyroscopic stabilization and maintenance of true bearing for elimination of effects of all ships' motions; 2) of proportional indication of the angular deviation of the target echo from the projector axis; and 3) the use of "aided tracking." The last named is an automatic means for keeping the projector moving so as to follow the target which is presumed to be moving on a steady course and at a steady speed. The sonar operator, from observations of the echo spot position, judges the deviation of the actual course and makes corrections accordingly.

The sonar problem as it develops is presented to both the operator and the submarine warfare (ASW) officer in the form of cathode-ray-tube displays. Because of the continuous receipt of sonar information, smooth data on depth, range, and bearing, or their geometric equivalents, can be presented to the ASW team through the use of computers.

If an antisubmarine (A/S) vessel is to hold sonar contact with, and attack, a fast target successfully, it must move at a speed exceeding that of the target by a considerable margin. At high speeds turbulent water flow about an unprotected sonar projector causes a prohibitive amount of noise. Existence of this problem is the inspiration for NRL's work in the development of sonar domes which are mechanically strong, sound-transparent streamlined housings used for the protection of sonar projectors from water turbulence.

The USS FOSS, EDE-59, prior to the present reporting, had been equipped by NRL with a sonar system embodying most of the features outlined above. The reports for this year on this program are mostly concerned with display problems because they are the significantly new features as contrasted with the day-by-day improvements in mechanical and electrical control functions. The displays are cathode-ray-tube presentations of sonar information. The so-called "wedge sweep" was introduced. The sonar beam is shown on the display as a fan-shaped area in which a momentarily brightened spot represents the echo, properly located in range (radius) and bearing deviation from the sonar axis. Effectiveness of this type of display, which is free from distortion, was demonstrated by the presentation of a "composite" sonar picture of the Morgantown Bridge piers and adjacent shoreline. The wedge sweep shows an extended target in correct aspect so that the target angles can readily be determined. A comparison between several "sector scan indicators" of different origins showed that they were equal in precision to the limit of error permitted by sonar echo fluctuation in the Potomac River where they were tested. Other improvements related to the aspect indicator and wedge sweep were reported. One report had to do with the introduction of miniature components in the construction of sector scan indicators; the other was the introduction of a cursor (pointer) which could be lined up with the angular position of the echo. This device was called the "train-error-corrector." Servo orders from the rotation of this cursor cause the projector to train so as to make the next echo signal register on the axis of the beam. In connection with the display problems, the ASAP (antisubmarine attack plotter) was modified so that it would deliver horizontal range. This is an advantage where weapons such as the "hedge-hog" are used.

Sonar Dome Development. — This is an important part of the general sonar systems program. Because sonar domes are a compromise between strength and sound transparency, an exact knowledge of the stresses to which the reinforcing

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members are subjected is of importance because the ideal but impossible dome would consist of a completely sound transparent structure having strength enough to resist the water forces. If the stresses in the reinforcing members were known exactly for a given sea condition, these members could be designed for minimum size and, therefore, minimum obstruction to the sound radiation pattern. A 60-inch dome in which electrical resistance strain gages had been mounted was tested in the Laboratory by mechanical loading. The strain gage deflections were recorded as a function of applied force. In a sense, this amounted to a "calibration." The dome was originally planned for installation on the USS WITEK but was later mounted on the USS FOSS. Because of the extreme difficulty in waterproofing the gages, many of them were ruined by salt water penetration. However, five of the gages held up, and with these valid stress determinations were obtained. With the five functioning gages, a satisfactory technique was worked out and preliminary information on stresses in some of the dome members was determined. On the basis of these tests an improved dome design was arrived at. Another dome with improved gage insulation is being made ready for future tests.

The 60-inch dome has a fineness ratio of 2 1/2:1 which is too small for the very high speed operations. Therefore, a dome twice as long, that is, having a fineness ratio of 5:1, was proposed some time ago and again in October, 1947. The costliness of manufacture of such a large dome by the methods used for the 60-inch dome was pointed out. A new type of construction was then worked out by the dome designers. The new departure in construction was the introduction of spot welding for joining the rubber panels instead of the use of bolted flanges. It turns out that by proper manipulation, steel reinforced rubber panels can be spot welded together with no damage to the rubber to form a good dome.

Helicopter and Blimp Sonar Research. — The effectiveness of sonar on surface vessels decreases rapidly as the operating speed increases because of rapidly rising noise background. The noise limitation becomes so troublesome when the chase demands speeds above 15 knots that sonar vehicles other than surface vessels must be seriously considered. Aircraft, namely, blimps and helicopters, capable of hovering, offer the greater promise. The Laboratory has therefore initiated the study of, and has prepared two kinds of "dunking" sonar systems for study of practicality. Both require the vehicle to hover. The transducer is lowered into the water and is held stationary so as to take advantage of the low noise level which varies with the sea-state. The aircraft are not vulnerable to torpedo attack. The sonar sweep rate in square miles of sweep per hour is high for two reasons--(a) the listening conditions are good because of low noise background, and (b) compared with ships, the aircraft have high values of acceleration and velocity over the water. The systems are promising because of recent developments in blimps and helicopters. The blimps have been greatly improved in hovering and sea keeping ability and in pay load. The helicopters also have recently been built with adequate pay load capability.

An electrostatic hydrophone having possible application to the blimp sonar systems was developed at NRL. This hydrophone is light, inexpensive, and is sensitive at audio frequencies. It consists of two foil-electrodes separated by a thin plastic film which prevents short circuit of the polarizing voltage. The compliance resides in the film of air included between the plastic film and one electrode. One variant of the electrostatic hydrophone was used in listening tests at Lakehurst in November, 1947, on the K65 blimp. Listening ranges of 4 1/2 miles were obtained. These were greater than the ranges obtained by NRL four years ago with blimp-towed hydrophones of piezoelectric crystal type. The good listening ranges were further encouragement to proceed with the airborne sonar program.

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The source of sound for the echo-ranging feature of the blimp system is a "broadcast" magnetostriction sound emitter constructed at NRL. It consists of eight stacks of thin nickel rings which are excited into circumferential mechanical vibrations by the magnetic field of a toroidal coil wound on each stack.*

A double-face crystal transducer for use with the helicopter sonar equipment was designed, constructed and tested at NRL. Five equipments are being prepared. The Edo Aircraft Corporation of Long Island City is building the electrical parts; the Wallace and Tiernan Company of Newark is building the hoist reels and NRL has constructed the five double-face crystal transducers. One reel has been received from the Wallace and Tiernan Company and is now undergoing performance tests at NRL.

Submarine Sonar System. -- The "XDG" is a complete sonar echo-ranging, listening, system having two separate and individually controlled 2-foot-diameter crystal transducers. The system incorporates many features which sonar experimentation to date has indicated to be necessary for improved performance. Some of them are: (1) stabilization, (2) accurate (±10' of arc) servo control of tilt and bearing, (3) large (2-ft-diam) transducer for sharp beam and high axial sound power, (4) triangulation for passive listening ranging (TLR), and (5) surface scanning by listening for surface targets.

One component of the system is the sound-transparent rubber dome which protects the projector from water noise. A mechanical test of one of the domes was made on the USS ARGONAUT in October, 1947. The greatest stress to which the dome will be subjected in service will result from the impact forces of waves striking the dome when the submarine is running awash into a heavy sea. The greatest deformation of the dome was expected to be a fore and aft deflection. To measure the maximum deflection, a scratch gage was arranged inside near the top. Mechanical aids were used to make sure that all air was removed. An earlier test resulted in destruction of a dome by crushing during the dives because air had accumulated inside it. During the October tests, about 40 shallow dives and one dive to 400 feet were made without damage to the dome. The maximum deflection, caused by wave impact, amounted to 1/8" which was well within the elastic limit of the dome.

Both projector units of the XDG equipment are now at the Laboratory. The entire system is assembled and is being thoroughly tested for accuracy and reliability insofar as that is possible in the laboratory. The equipment will be a unique research tool. When installed on the submarine, quantitative information can be obtained on sonar fundamentals such as (1) determination of optimum transducer depth as a function of refraction conditions, and (2) range increase as a function of acoustic power. Accuracy and reliability have been improved by introducing modification where indicated by barge tests.

BIO-ACOUSTICS (S08)

During this reporting year extensive research was conducted in the field of physiological acoustics. This included a study of the high-power siren. The frequencies of high intensity sound available are, in the high range, 7,200 and 30,000 cycles per second and, in the low range, 1,200 and 5,000 cycles per second. The siren has been mounted in a sound chamber where it is expected that 10,000 dynes per square centimeter sound field can be developed.

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* A more detailed discussion of this equipment will be found in the section on "Transducers."

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A study was also conducted on the noise output of a grounded P-80 jet plane. Over-all sound levels proved to range from 118 db to 130 db at distances of 50 ft to 100 ft and frequencies between 30 and 10,000 cycles per second. "Audible P-80 Jet Aircraft Noise," (S-3266, Unclassified) summarizes the results of this research.

The Naval Medical Research Institute is cooperating with NRL scientists in the collection of factual data concerning the application of sound and vibration investigative techniques to biological processes. To this end instruments were assembled for the purpose of measuring the velocity and absorption of sound in animal tissues. In January, 1948, a pulse-phase method was reported. To gain skill and confidence in the method, it was used for measurements on liquids. It has advantages over the interferometer. It is more sensitive and can be used to measure highly absorbent media. In April, 1948, it was reported that the method was successfully applied to tissues. The accuracy was one part in fifteen hundred at a frequency of 5 megacycles. Consistent results were reported for pig tissues. The velocity is different for the different tissues. For example, the lowest velocity was obtained through fat--about 1 percent lower than through saline solution. All other tissues exhibited velocities from 3 to 6 percent higher than did the saline solution.

Another instrumentality for medical research is the High Amplitude Vibration Machine which was reported as being 95 percent complete in February, 1948. This machine is intended for studying the "normal modes" of the human body. It has a load capacity of 300 pounds. The frequency is variable from 2 to 50 cycles per second and the amplitude is variable from 0 to 2 inches with a stress limitation corresponding with 15 "g" units.

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APPENDIX A

NRL Reports Prepared in the 1948 Fiscal Year

The following list of NRL reports, grouped according to field of research, includes those reports prepared in the 1948 fiscal year. Reference to each of the reports listed in this Appendix is made in the text of the report. In some cases, in order to give a more comprehensive reference to published NRL literature on the problem or subject under discussion, reports which do not fall within that period are also listed in the textual material. Such reports are not included in this Appendix.

CHEMISTRY

C-3100	"The NRL Fog Cabinet and the A & N Aeronautical Specification Humidity Cabinet," by H. R. Baker and D. T. Jones, July 1947	(U)
C-3114	"Volatile Compounds as Fungicides," by Walter L. Clark, Lt., USNR and John M. Leonard, July 1947	(U)
C-3147	"Hydrides and Borohydrides of Light Elements," by H. I. Schlesinger and A. E. Finholt, August 1947	(U)
C-3152	"Quarterly Progress Report No. 4 on the Measurement of the Physical and Chemical Properties of the Sodium-Potassium Alloy," C. T. Ewing, R. S. Hartman and H. B. Atkinson, Jr., July 1947	(R)
C-3163	"Improvement of Antifouling Paint for Naval Aircraft Hull-Bottoms," by Jack E. Cowling, 1 August 1947	(U)
C-3180	"Preparation of Organophosphorus Compounds," by E. J. Kohn, U. E. Hanninen and R. B. Fox, 23 September 1947	(U)
C-3191	"Second Report on the Thermal Evaluation of Formvar Resin," Thomas D. Callinan, 20 October 1947	(U)
C-3192	"Investigation of Silicone Polymer Fluids Part VIII, High Temperature Performance of Silicone Fluids in Journal Bearings," by J. E. Brophy, J. Larson and R. O. Militz, 30 October 1947	(U)
C-3208	"Hydrides and Borohydrides of Light Elements, Progress Report No. XXVIII," by H. I. Schlesinger and George W. Schaeffer, 4 December 1947	(U)
C-3243	"Quarterly Progress Report No. 6 on the Measurement of the Physical and Chemical Properties of the Sodium-Potassium Alloy," C. T. Ewing, R. C. Werner, E. C. King and R. A. Tidball, 25 February 1948	(C)

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C-3201	"Quarterly Progress Report No. 5 on the Measurement of the Physical and Chemical Properties of the Sodium-Potassium Alloy," by H. B. Atkinson, Jr., R. R. Miller and C. T. Ewing, 9 December 1947	(C)
C-3251	"The Catalytic Hydrogenation of Some Aryl-Substituted Aliphatic Acids," F. L. Schmehl and N. L. Smith, 5 March 1948	(U)
C-3262	"First Report on Investigation of the Plate Materials of the Lead Acid Cell, Compound Formation Between Lead Monoxide and Lead Sulfate," J. J. Lander, 22 March 1948	(U)
C-3267	"The Second Report on Oleophobic Monolayers, Temperature Effects and Energies of Adsorption," W. C. Bigelow, E. Glass and W. A. Zisman, 10 March 1948	(U)
C-3273	"Low Temperature Crankcase Lubricants," Carl Lamb and C. M. Murphy, 30 March 1948	(U)
C-3274	"Infrared Spectra of Pure Hydrocarbons," D. C. Smith, 6 May 1948	(U)
C-3275	"The Loss Factor of Formvar," Thomas D. Callinan, 5 April 1948	(U)
C-3277	"The Anodic Behavior of Aluminum and Zinc Alloys in Sea Water," Thomas P. May, S. Schuldiner and J. Burbank, 13 April 1948	(U)
C-3284	"Investigation of the Hydrolysis of Halogenated Hydrocarbon Compounds," by Kenneth L. Temple and John K. Wolfe, 13 May 1948	(U)
C-3285	"Infrared Spectra of Some Natural Elastomers," R. A. Saunders and D. C. Smith, 17 May 1948	(U)
C-3286	"Evaluation of Adhesion of Organic Coatings to Metal Surfaces by Ultrasonic Vibrations," Saul Moses, 19 May 1948	(U)
C-3287	"Quarterly Progress Report No. 7 on the Measurements of the Physical and Chemical Properties of the Sodium-Potassium Alloy," C. T. Ewing, H. B. Atkinson, Jr., and T. K. Rice, 24 May 1948	(U)
C-3289	"Fungus Inhibitive Properties of Organic Compounds, Part I Hydrocarbons and their Halides," John M. Leonard and Warren E. Weaver, 27 May 1948	(U)
C-3311	"Boron Hydrides, A Study of Chemical and Physical Properties," S. H. Smith, Jr., and R. M. Newhall, 16 June 1948	(C)

ELECTRICITY

E-3145	"Cable Thermo Curves," W. H. Askew, 14 July 1947	(R)
E-3160	"Moisture Investigation of Cable," W. H. Kohlmann, 21 August 1947	(R)

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E-3169	"Variable Speed Constant Frequency Alternator," E. L. Brancato, 5 September 1947	(U)
E-3206	"Stability Specification for Voltage Regulators," J. W. Pobst, 22 April 1948	(U)
E-3228	"Development of A Method of Obtaining A Uniform Abrasion Test for Aircraft Electrical Cable," William A. Ritchie, 3 February 1948	(R)
E-3237	"General Improvement of Control Element of Reverse-Current Cutouts," J. M. Marzolf, 9 February 1948	(U)
E-3292	"Time Delay Relays for Aircraft Applications," W. M. Tucker, 9 June 1948	(U)
E-3295	"Development of A Shock Resistant Indicator Light," J. D. Haynsworth, 9 June 1948	(R)

MECHANICS

S-3151	"Shock and Vibration Bulletin No. 4," July 1947	(C)
S-3153	"Vibration Isolator for Aircraft Voltage Regulator," Carl J. Bastien, July 1947	(U)
S-3181	"Shock and Vibration Bulletin No. 5," September 1947	(C)
S-3186	"Characteristics of the 3 Ft-Lb Vibration Machine," R. W. Conrad, 7 October 1947	(U)
S-3195	"Development of Instrumentation Techniques for Measuring Periscope Vibration," A. N. Ciaffardini, 4 November 1947	(R)
S-3200	"Shock and Vibration Bulletin No. 6," November 1947	(C)
S-3207	"A Determination of the Elastic Constants for Beta Quartz," E. W. Kammer and T. E. Pardue, 3 December 1947	(U)
S-3216	"Ultrasonic Measurement of Wall Thickness in Diesel Liners," F. W. Struthers, 5 January 1948	(U)
S-3229	"Shock and Vibration Bulletin No. 7," January 1948	(C)
S-3276	"Shock and Vibration Bulletin No. 8," March 1948	(U)
S-3290	"Shock and Vibration Bulletin No. 9," April 1948	(C)
F-3302	"The Equivalent Static Accelerations of Shock Motions," J. P. Walsh and R. E. Blake, 21 June 1948	(U)

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METALLURGY

M-3148 "The Use of Hyper Atmospheric Pressures in the Feeding of Steel Castings," E. T. Myskowski, July 1947 (U)

M-3159 "The Temperature Coefficient of Young's Modulus of Masumoto's Low Expansion Alloy," H. E. Stauss, D. S. Billington, R. N. Dean and F. E. Martin, 15 August 1947 (U)

M-3183 "The Determination of Some Common Alloying Elements in Aluminum and Its Alloys," William Zimmerman III, 30 September 1947 (U)

M-3254 "The Value of Pressure Tests and Radiographs of Gun Metal Castings," William H. Baer, 8 March 1947 (U)

M-3296 "Stress Relief of Gray Cast Iron," J. H. Schaum, 9 June 1948 (U)

M-3304 "Tensile and Transverse Testing of Gray Cast Iron," J. H. Schaum, 23 June 1948 (U)

OPTICS

N-3097 "Optical Radiation from Acid-Aniline Jet Flames," J. A. Curcio and C. P. Butler, July 1947 (C)

N-3256 "Comparison of Colorimetric Methods - Determination of Color Characteristics of Some Corning Filters and Fluorescent Cloths," L. R. Furlong, 9 March 1948 (U)

N-3257 "Brightness and Polarization of the Daylight Sky," E. O. Hulburt, February 1948 (U)

N-3263 "Survey of the Brightness of the Night Sky," E. O. Hulburt, April 1948 (U)

N-3264 "A Multi-Range Electronic Apparatus for Measuring and Recording Phosphorescent Decay," W. S. Plymale, Jr. 25 March 1948 (U)

PHYSICS

O-3064 "Fourth Partial Report on Gas Pulsator," D. W. Baker G. C. Milak, and C. D. Porter, August 1947 (C)

R-3171 "Upper Atmosphere Research Report No. IV," 1 October 1947; and (U)
R-3358 "Upper Atmosphere Research Report No. V," 17 June 1948; H. E. Newell, Jr., and J. W. Siry

E-3176 "Sliding Contacts at High Altitudes, Experimental System for Carbon Brush Investigations," E. F. Harmon, 23 September 1947 (U)

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S-3187	"Survey of Inorganic Piezoelectric Materials," Paul H. Egli, 10 October 1947	(U)
N-3189	"Low Voltage Self-Quenching Geiger Counters," S. H. Liebson and H. Friedman, 24 October 1947	(U)
P-3199	"Concluding Report of the Joint Army-Navy Atmospheric Electricity Research Project at Minneapolis, Minn.," G. D. Kinzer, 12 November 1947	(U)
E-3211	"Investigation of the Performance of Tungsten-Cobalt Plated Slip Rings and Commutators," Billy M. Horton, 17 December 1947	(U)
N-3212	"Eclipse Area and Eclipse Function Calculations," David B. Beard, 7 January 1948	(U)
R-3236	"A Navy Shipboard Neptune Program," T. A. Bergstralh, H. E. Newell, Jr. and M. W. Rosen, 9 February 1948	(C)
P-3252	"Gas Pulsator - Pulse Jet Fifth Partial Report," G. C. Milak, 5 March 1948	(C)
N-3265	A Study of Multiple Compton Scattering," W. R. Faust, C. Fiddler, and M. H. Johnson, 26 March 1948	(U)

RADIO

R-3059	"Analysis of Channel Interference on Communication Systems (225 to 400 Mc)," A. W. Walters, 1 August 1947	(C)
R-3087	"A Wide-Range Look-Through Receiver," I. H. Page and R. E. Ellis, July 1947	(R)
R-3101	"The Development of a Guided Missiles Telemetering System for KUW-1," A. J. Stecca and V. J. Guethlen, July 1947	(U)
R-3111	"Statistical Methods in the Design and Development of Electronic Systems," L. S. Schwartz, July 1947	(U)
R-3119	"Interim Report on the Development of Drive Units and Control Mechanism for Airborne Automatic Search and Jam System--- AN/APQ-33 (XB)," J. H. Markell, August 1947	(C)
R-3122	"Bibliography of Antenna Reports," Antenna Research Section, July 1947	(R)
R-3123	"Video Mixing and Minimum Detectable Signal in the SPS-2 Radar," H. W. Lance, G. D. M. Peeler, and C. R. Randall, 11 September 1947	(C)
R-3149	"Evaluation of the M 6700 Radar D.F. Antenna," K. O. Hornberg, August 1947	(C)

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R-3150	"Cycle Matching for Standard Loran," by J. W. Brogden, H. D. Cubbage, and B. H. Weston, July 1947	(C)
R-3154	"Amplitude and Frequency Modulation for Facsimile Transmission and Other Applications," A. D. Watt, September 1947	(U)
R-3155	"Characteristics of Cavity Resonators made of Fused Quartz," H. L. Wuerffel and L. Schlesinger, August 1947	(C)
R-3157	"Spectral Emissivity and Electron Emission Constants of Thoria Cathodes Formed by Cataphoresis," T. E. Hanley, 12 August 1947	(U)
R-3158	"Investigation of Oscillator Circuits for Use with CR-9/U Over-Mode Crystal Units," Bertram C. Hill, Jr., and Sylvaine L. Kenyon, 1 November 1947	(R)
R-3161	Electrostatic Deflection Systems for Plan Position Indicators," Edward V. Phillips, 22 August 1947	(U)
R-3162	"Some Theoretical Considerations in the Design of Directional-Null-Type Antennas," C. V. Parker, 1 August 1947	(U)
R-3166	"Single Tube Harmonic Generator Design," H. H. Grimm, September 1947	(U)
R-3167	"Transfer Characteristics of a Bridged Parallel-T Network," Charles F. White, 27 August 1947	(U)
R-3168	"Second Interim Report on a System for High Speed Communications by Television," H. Gordon and L. L. George, May 1947	(C)
R-3171	"Upper Atmosphere Research Report No. IV," H. E. Newell, Jr. and J. W. Siry, 1 October 1947	(U)
R-3173	"X-Band Antenna for AN/APQ-33(XB) Jam System," K. W. Bewig, 21 July 1947	(C)
R-3174	"Development of A Zero-Drag VHF Communications Antenna for Aircraft," E. N. Keith, 8 September 1947	(C)
R-3175	"A Modulator for Noise Waveforms of High Jamming Effectiveness," R. S.Badessa, 22 September 1947	(C)
R-3177	"The Relay Interpolator - A Description of Its Operation," B. L. Sarahan, 25 September 1947	(R)
R-3179	"Development of Antennas for Use With Link Verification System," A. M. Winzemer, 24 September 1947	(U)
R-3182	"Direction Finder Bandwidth Requirements," S. F. George, 1 October 1947	(U)

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R-3184	"Survey of Rapid-Scanner Principles," A. S. Dunbar, October 1947	(C)
R-3185	"The AN/ARC-19 (XN-1) Airborne Multichannel Communication System - Its Development, Evaluation, and a Proposal for an Improved System," J. E. McGeogh, J. H. Dunn, and G. K. Jensen, 27 October 1947	(R)
R-3188	"Lark-Wasp Guided Missile Seminar," Arthur S. Locke, July 1947	(C)
R-3190	"Investigation and Study of the AM Reduction and Downward AM Characteristics of Three Forms of Ratio-Type FM Detector," D. R. Maxson, 28 October 1947	(R)
R-3193	"Calculation of Doubly Curved Reflectors for Shaped Beams," A. S. Dunbar, 3 November 1947	(R)
R-3194	"Development and Performance of a Ratio-Type FM Detector as Applied to the Model RDO Receiving Equipment," D. R. Maxson, 3 November 1947	(U)
R-3196	"Missile Guidance by Jet Impulse," Duncan Harkin, 7 November 1947	(C)
R-3197	"Propagation of Electromagnetic Waves Through Propellant Gases," F. Malcolm Gager, 6 November 1947	(C)
R-3198	"Development of a Highly Stable Crystal Controlled Oscillator-Exciter," E. R. Longman and J. Awramik, Jr., 6 November 1947	(C)
R-3202	"Calculation of the Attenuation of Electric Field Strength," H. J. Peake, 16 December 1947	(U)
R-3203	"Lark Telemetering Antennas," E. N. Keith and D. H. Russell, 20 November 1947	(C)
R-3204	"Direct Detection of Microwaves," B. A. Lengyel, 21 November 1947	(U)
R-3205	"Microwave Q Measurements in the Presence of Series Losses," L. Malter and G. R. Brewer, 18 May 1948	(U)
R-3209	"S-Band Propagation With Acid-Aniline Flame Barriers," F. M. Gager, E. N. Zettle, H. M. Bryant, and F. E. Boyd, 5 December 1947	(C)
R-3210	"Ultrahigh-Frequency Antenna Considerations for Radiation Measurements," Harold E. Dinger and George E. Leavitt, 16 December 1947	(U)
R-3213	"Circularly Disposed Antenna Arrays," James H. Trexler, 18 December 1947	(C)

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R-3214	"Antenna Radiation Patterns of KUW-1 Missile," Maxime G. Kaufman, 5 January 1948	(U)
R-3215	"A Graphical Method for Computing Short Impedance Matching Transformers," C. B. Barker, 5 January 1948	(U)
R-3217	"Omnidirectional Intercept Antenna for Submarines in the Frequency Range 1000 to 4000 Mc," William E. Withrow, 5 January 1948	(C)
R-3218	"Tests of 200 Megacycle Echo Boxes and Improvements in Model OAA-2," Walter J. Brinks, 7 January 1948	(R)
R-3219	"General Purpose Audio Amplifier," R. P. Lett, 8 January 1948	(U)
R-3220	"Radar Area Measurements of V-2 Rockets," F. C. Macdonald, 9 January 1948	(R)
R-3221	"Further Design and Development of Components for Simultaneous Lobing Radar Tab," H. L. Gerwin and A. E. Hastings, 13 January 1948	(C)
R-3223	"Millimeter Wave Research - Components for Millimeter Wavelength Range," Harold Herman and Robert J. Coates, 20 January 1948	(U)
R-3224	"Antenna for Radar Bomb Director Mark 5 (AN/APB-2)," A. S. Dunbar, 22 January 1948	(C)
R-3232	"Comparison of AM and Narrow-Band FM UHF Communication Systems - Appendix C: Design and Performance Characteristics of Equipment Employed," W. E. W. Howe and A. R. Rumble, 11 March 1948	(R)
R-3234	"Comparison of AM and Narrow-Band FM UHF Communication Systems - Appendix E: Shipboard Studies and Investigations," D. McClenon, 8 March 1948	(R)
R-3235	"Comparison of AM and Narrow-Band FM UHF Communication Systems - Appendix F: Airborne Studies and Investigations," F. J. Hollweck	(R)
R-3238	"Preliminary Report on Electromagnetic Wave Propagation in a Composite Medium," W. S. Ament, February 1948	(U)
R-3239	"Flight Tests of a Ground Speed Indicator Over Measured Runs," C. L. Estes and E. F. McClain, 11 February 1948	(C)
R-3240	"Some Characteristics of a Proposed Conical-Scan Radar Homing Equipment for the Skylark Missile," Anthony J. Stecca and Maxime G. Kaufman, 15 September 1947	(C)

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R-3241	"Miniature S-Band Telemetering Transmitter for Guided Missiles," Victor J. Guethlen and Anthony J. Stecca, 16 February 1948	(R)
R-3242	"Evaluation Report, AN/ARD-4, Serial No. 1, VHF Airborne Radio Direction Finder," Allan G. Thompson, 18 February 1948	(C)
R-3244	"A Finite Difference Solution of Recurrent Networks," B. N. Navid, 1 March 1948	(U)
R-3245	"Characteristics of Directional-Null Antenna Patterns Produced by Multi-Element Arrays," C. V. Parker, 1 March 1948	(U)
R-3246	"The MTI Conversion Unit for SC-SK Series Radar," T. H. Chambers, 2 March 1948	(C)
R-3248	"Psychological Studies of Tracking Behavior - Part I: Rate and Time Characteristics of Simple Corrective Movements," Lloyd V. Searle, 3 March 1948	(U)
R-3249	"Psychological Studies of Tracking Behavior - Part II: A Study of the Acceleration Pattern of Quick Manual Corrective Responses," Franklin V. Taylor and Henry P. Birmingham, 3 March 1948	(U)
R-3250	"A Precision Range Delay Unit," Arno M. King, 4 March 1948	(C)
R-3253	"Response of an Airframe to Sinusodial Wing Flap Deflection," James W. Titus, 5 March 1948	(C)
R-3258	"The Series Peaking Transformer - A Current-Zero Trigger Source," L. D. Breetz, 16 March 1948	(R)
R-3259	"Evaluation of Model X-DBH Radio Direction Finder," John J. Conlon, 16 March 1948	(U)
R-3261	"Incidental Flame Modulation of S-Band Continuous Wave Radiation," F. Malcomb Gager, H. H. Grimm, R. C. Peck, and G. D. Morehouse, 19 March 1948	(C)
R-3268	"Antenna Feeds for Tracking Radars," A. E. Hastings, 29 March 1948	(C)
R-3269	"An Investigation and Analysis of the Radiation Spectrum of the Model TDP-1 Loran Transmitter," A. W. Coven and J. W. Brogden, 29 March 1948	(C)
R-3271	"An Automatic Lightweight Homing System," G. P. Ohman, 30 March 1948	(C)

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R-3272	"A Network Performance Analyzer," Charles F. White and Louis A. Marzetta, 30 March 1948	(U)
R-3278	"IFF System Defruiting with a Mercury Delay Line," J. R. Parsons, 14 April 1948	(C)
R-3280	"Proposed Constant True Bearing Homing System for Skylark," Peter Waterman, C. L. Key, Jr., and C. H. Dodge, 16 April 1948	(C)
R-3281	"Theory and Design of Resonant Transformer-Coupled Loop-Antenna Input Systems for VLF Reception," S. V. Fratianni, 28 April 1948	(R)
R-3282	"The Measurement of Vulnerability to Jamming," B. W. Miller, 28 April 1948	(C)
R-3283	"An X-Band Frequency Measuring System," I. K. Munson, 19 May 1948	(R)
R-3288	"Analysis of Low Frequency Pulses," J. W. Brogden, H. D. Cubbage, and B. H. Weston, 24 March 1948	(C)
R-3293	"The Fresnel Zone Plate Antenna," I. Maddaus, Jr., 3 June 1948	(U)
R-3297	"An Electronic Error Integrator," Henry P. Birmingham, 10 June 1948	(U)
R-3298	"A Device for Use in Studying the Pattern of Hand Movements," Henry P. Birmingham, 10 June 1948	(U)
R-3301	"A PPI Parameter Study System," T. B. Jackson, 17 June 1948	(C)
R-3303	"Some Servo System Sinusoidal Studies," Charles F. White, 22 June 1948	(U)
R-3305	"Development of Electron Tube for Switching Radio Frequency Power," W. H. Flarity, 23 June 1948	(C)
R-3306	"The Electron Wave Tube - A Novel Method of Amplification and Generation of Microwave Energy," Andrew V. Haeff, 24 June 1948	(U)
R-3307	"A Spherical Balloon with Internal Corner Reflector for Radar," Sam K. Brown, Jr., 30 June 1948	(C)
R-3318	"Guided Missile Seminar, September 1947," A. S. Locke	(C)
R-3320	"Study of Moduplex Characteristics," A. D. Watt, 14 July 1948	(R)
R-3324	"Development of a VHF Frequency Converter Unit for the AN/MKR-4 Telemeter Receiving Equipment," Paul T. Stine and Kenneth A. Morgan, 22 June 1948	(R)

SOUND

S-3266	"Audible P-80 Jet Aircraft Noise," W. Wathen-Dunn, 26 March 1948	(U)

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