Air Force Cambridge Research Laboratories

REPORT ON RESEARCH

For the Period July 1963 — June 1965

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AFCRL-65-595

Report on Research at AFCRL

JULY 1963 — JUNE 1965

SURVEY OF
PROGRAMS AND
PROGRESS

THE AIR FORCE CAMBRIDGE
RESEARCH LABORATORIES
OFFICE OF
AEROSPACE RESEARCH
BEDFORD MASSACHUSETTS
SEPTEMBER 1965

Foreword

This is the third in a series of reports on research at the Air Force Cambridge Research Laboratories. The report covers a two-year interval, as will succeeding reports in this unclassified series. On alternate years, the AFCRL report will cover classified programs. The first such report on classified programs will be published in 1966. This report was written primarily for Air Force and DoD managers of research and development — and more specifically for the managers in our Headquarters office, the Office of Aerospace Research. But it is hoped that it will be of interest and value to a much broader audience. To encompass this broader audience and to make the content more meaningful, we have attempted to relate, by means of survey discussion, our programs to the larger scientific field of which they are a part. For the Air Force research manager, we have attempted to indicate the relevance of AFCRL research to Air Force needs. With respect to the latter, however, we have exercised caution. It is quite easy to be superficial in this matter because almost all research can be shown to have such relevance. Relevance is measured in degrees. The potential of AFCRL for contributing to Air Force operational capabilities is dependent foremost upon AFCRL strength as a research laboratory. The research programs covered in this report reflect both the fulfilled aspects of this potential and the growing potential for future contributions to the overall Air Force mission.

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1 The Air Force Cambridge Research Laboratories

The Air Force Cambridge Research Laboratories are an element of the United States Air Force. The programs of AFCRL are concentrated in those scientific areas where, in the judgment of AFCRL scientists and research managers, there is likely to be a payoff in terms of enhanced Air Force operational capability. All the research discussed in the succeeding chapters of this report is germane to problems in reconnaissance, surveillance, detection, communications, information processing and use, and to aircraft and missile operations.

This research is largely concerned with basic physical mechanisms and environmental phenomena. The correspondence between these research studies and Air Force operational requirements is not necessarily a direct one. Most often it is highly indirect. One part of the AFCRL role is to conduct research that may lead to new requirements. The relationship between science and new technologies has received abundant commentary elsewhere. The relationship is now accepted as self-evident fact, and is, of course, the fundamental assumption underlying Air Force support of research.

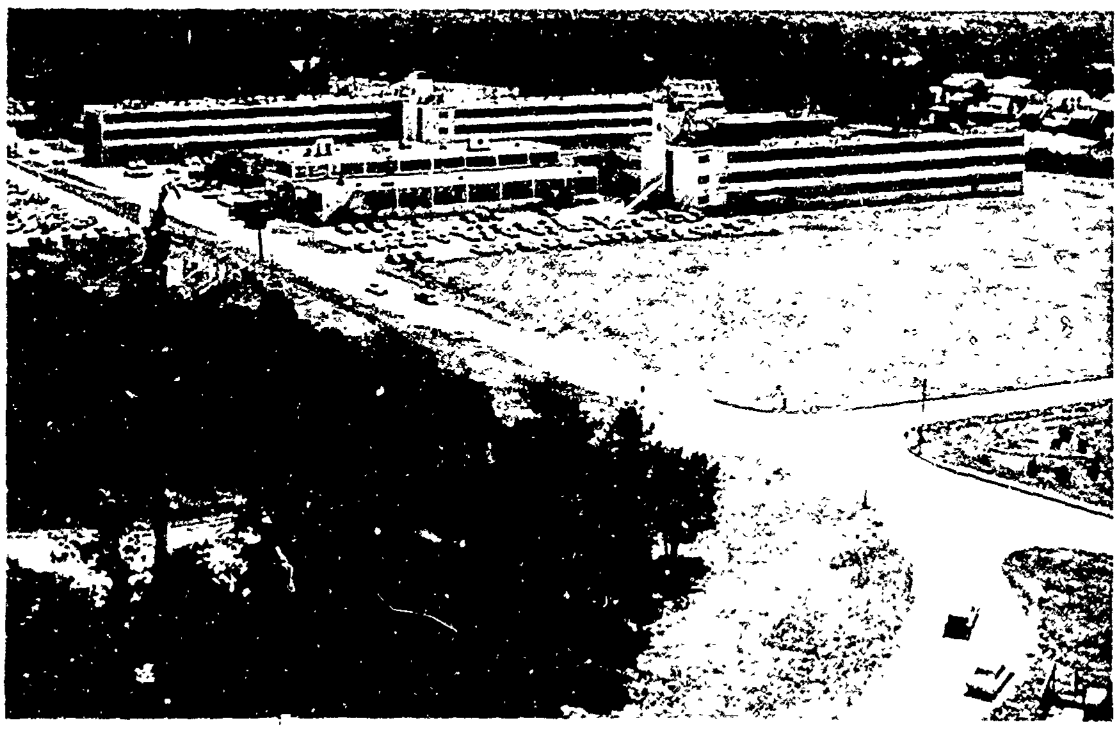
As a contributing member of the scientific community in its own right, AFCRL has a clear and discerning view of the accumulated product of science and the capability of drawing upon those parts of this accumulated product that have a relevance to Air Force requirements.

In the approximately 15 percent of

the AFCRL program that is classified, AFCRL is most directly and intimately concerned with improved Air Force operational capabilities. The classified research program at AFCRL will be covered in a separate report to be issued in 1966.

AFCRL MISSION: The mission of AFCRL is to conduct — to carry out, to do — basic and applied research in the environmental sciences and in certain areas of the physical sciences. A secondary aspect of the mission is to support, under contract, research in these two broad categories. Research in the environmental and physical sciences can be translated to mean geophysics and electronics. AFCRL is the Air Force center for research in geophysics and is the center for much Air Force research in electronics. By geophysics is meant meteorology, geology, geodesy, gravity, the dynamics of the upper atmosphere, astrophysics, astronomy and so on. Electronics research at AFCRL is focused on microwave physics, solid state physics and the information sciences.

AFCRL is an in-house laboratory. This might be taken to mean that all of its programs are wholly carried out by AFCRL personnel. This is not the case at AFCRL — or at any large research laboratory. A design concept, for example, may originate in-house, but a



More than 900 of AFCRL's 1108 employees are located in the main laboratory complex at L. G. Hanscom Field in Bedford, Mass. In addition to these buildings, AFCRL maintains a number of field sites in eastern Massachusetts, in New Mexico and in California.

practical working instrument or device based on this concept may be completed by others under contract. Inhouse research, as viewed by AFCRL, is research that is conceived by, formulated by, directed by, and conducted at least in part by an AFCRL scientist. This scientist is ordinarily responsible for final data analysis and interpretation — but even in this respect he may be helped by others under contract.

There is another aspect of the AFCRL mission that needs emphasis. AFCRL has the responsibility for working on certain specific, time-oriented problems for the Air Force that are in urgent need of solution. Where AFCRL has the talent and the capability to contribute to the solution of such problems, it also has the obligation to respond to the need. This obligation is one to which AFCRL and its scientists are keenly attuned.

Closely related to this aspect of the AFCRL mission is that of serving as advisors in many areas of science and technology. AFCRL scientists serve on more than 45 Air Force, DoD, other Governmental, and international committees, boards, study groups and panels. These groups have a number of functions: to evaluate systems concepts, to shape military programs, to coordinate activities and programs, or simply to provide a forum for the exchange of information and views.

At regularly scheduled commanders conferences, OAR Commander Major General Don R. Ostrander (extreme left) meets with the commanders of the various OAR elements and members of their staffs to review research and management programs.

ORGANIZATIONAL PERSPECTIVE: The Air Force Cambridge Research Laboratories report to the Office of Aerospace Research (OAR). OAR has its headquarters in Washington, D. C., and in turn reports directly to Hq USAF. OAR is responsible for the Air Force research mission, and is organizationally separated from the Air Force development and much applied research activity. There is frequent misunderstanding on this matter. Most Air Force development and applied research activity is carried out by a separate command, the Air Force Systems Command.

AFCRL is the largest of the several research laboratories and offices administered by the Office of Aerospace Research. In terms of people, OAR Headquarters together with all the laboratories under its command numbers less than 2000 persons. Of this number, about 1100 are at AFCRL.

Other laboratories comprising OAR are the Office of Scientific Research, in Washington, D. C., which relies exclusively on contracts in carrying out external research across a broad spectrum of scientific disciplines; the Aerospace Research Laboratories, at Wright-Patterson AFB, Ohio, an in-house research laboratory working in the fields of metallurgy, thermomechanics, hypersonics and fluid dynamics; the Frank J. Seiler Research

On 18 October 1965 (subsequent to the time period of this report) Colonel Robert F. Long (right) was appointed new AFCRL Commander, succeeding Brigadier General Leo A. Kiley (left).

Laboratory located at the USAF Academy, Colorado, engaged in the physical and engineering sciences, and the Operations Research Office, located at Holloman AFB, New Mexico, which is concerned with systems analysis. In addition, OAR maintains small liaison offices at Patrick AFB, Florida, and Vandenberg AFB, California, and at the Space Systems Division, in Los Angeles. Foreign operations are conducted through offices in Brussels and Rio de Janeiro.

The Office of Aerospace Research, during the period of this report, was under the command of Major General Don R. Ostrander. Serving as General Ostrander's Vice Commander was Brigadier General Ernest A. Pinson, who upon the retirement of General Ostrander on 15 October 1965 will become new Commander of the Office of Aerospace Research.

AFCRL, at the termination of this reporting period, was under the command of Colonel Leo A. Kiley. (Subsequent to the reporting period, two significant command events occurred: Colonel Kiley was elevated to the rank of Brigadier General on 20 August 1965 and was soon thereafter named Commander of the Air Force Missile Development Center, New Mexico. Colonel Robert F. Long, then Commander of the 6th Weather Wing, Air Weather Service, was appointed new AFCRL Commander on 18 October 1965.)

Colonel Kiley, prior to assuming command of AFCRL on 27 October 1964, served as AFCRL Vice Commander under Brigadier General B. G. Holzman who retired on that date. Named the new AFCRL Vice Commander on 1 July 1965 was Colonel James L. Dick. Before joining AFCRL, Colonel Dick served as Chief of Plans and Programs, Air Force Weapons Laboratory, New Mexico.

AFCRL is made up of nine laboratories organized roughly along disciplinary lines. But in the special sense that the research in each laboratory is related to present and anticipated Air Force needs — weather modification, prediction of solar proton showers, better communications — the laboratories are mission oriented. This duality is common to almost all research laboratories, even those associated with universities. Such laboratories tend to be organized along disciplinary lines, while functionally much work is mission oriented.

The titles of AFCRL's nine laboratories indicate something of the breadth and diversity of the AFCRL program. These titles are: Upper Atmosphere Physics, Microwave Physics, Space Physics, Terrestrial Sciences, Optical Physics, Data Sciences, Meteorology, Solid State Sciences and Aerospace Instrumentation.

Of the AFCRL personnel complement

of 1108, 194 are military, and 914 are civilian. The 1108 figure is an increase of 13 persons over the 1 July 1963 figure given in the previous AFCRL report. But this figure does not fully reflect AFCRL size. Much administrative support — procurement, personnel, maintenance, and so on — is furnished by the AFSC Electronics System Division at L. G. Hanscom Field. In terms of people, this support constitutes about 300 man years. Furthermore, much of AFCRL's work could not be done without the help of personnel from other Air Force agencies — the Air Weather Service, and the personnel at the various Air Force rocket and missile ranges. The turnover rate of AFCRL scientific personnel is about five percent a year, a percentage somewhat lower than the national average for research laboratory personnel.

Almost 600 AFCRL employees have degrees — 219 bachelors, 233 masters and 141 doctorates. The 141 doctorate figure represents an increase of 25 over the figure of two years ago. While the proportion of advanced degree holders in any research laboratory is less than an infallible guide to the capacity of that laboratory for creative research (itself an ill-defined commodity), the statistic is nevertheless one guide in an area where there are few others. A more valid complementary index, perhaps, is the number of papers published and presented. During the two-year period from July 1963 to June 1965, AFCRL scientists published 404 papers in scientific journals, presented 503 papers at scientific meetings and issued 208 in-house research reports. These papers are listed at the end of each laboratory chapter in this report.

Flight crews for AFCRL airborne experiments are provided by AFSC's Electronics Systems Division at Hanscom Field. Here a crew returning from a weather observation mission is interviewed by the press.

FY-1964 AND FY-1965 BUDGETS: The research programs discussed in the following chapters of this report were conducted at a cost of $125 million. This is the combined total of AFCRL's FY-1964 and FY-1965 budgets. The FY-1964 budget was $66.8 million, the FY-1965 budget $58.2 million. Thus, there was an $8.6 million decrease in the FY-1965 budget from the previous year. In comparing the FY-1965 budget with that of FY-1963 ($74.5 million, the largest budget in AFCRL history) there has been a decrease of $16.7 million.

The primary reason for this large decrease is the completion of certain large programs funded by the Defense Atomic Support Agency and the Advanced Research Projects Agency. DASA funding for AFCRL's participation in the 1962 series of atomic tests in the Pacific and ARPA funding of the Arecibo Radio Observatory in Puerto Rico accounted for a large portion of the inordinately large FY-1963 budget. Reduced funding from the Air Force Systems Command accounted for much of the recent decrease between FY-1964 and FY-1965.

The AFCRL budget is derived from many agencies. Sources of FY-1964 and FY-1965 funds are shown in the accompanying tables. The budget figures given in these tables are not intended to represent a total cost accounting for operating AFCRL. Many costs such as salaries of military personnel, services provided by the air base on which AFCRL is a tenant, and assistance in conducting field operations given by other Air Force and Government agencies, are not reflected in the figures shown. The figures include the money received by AFCRL for contract research, civilian salaries, equipment, travel, and general operational costs. About $11.3 million of the FY-1965 budget was expended for civilian salaries.

The funds received from AFCRL's headquarters, OAR, and to a lesser extent those received from AFSC are used to support research of a continuing, long range nature. More discretion is provided AFCRL administrators and scientists in the expenditure of funds from these two sources than is allowed in the expenditure of funds from other sources. Funds from other agencies are earmarked for specific research projects.

The reporting period witnessed one major change in the allocation and management of AFCRL's funds. This change affected only certain programs of a more applied research nature in electronics. These programs fall under a category bearing the designation, "Electromagnetics, Other." AFCRL was asked to identify all applied electronics research programs so that management responsibility for these programs could be transferred to AFSC's Research and Technology Divi-

TABLE 1
SOURCES OF FY-1964 FUNDS

OAR		$43,853,000
AFSC		12,646,000
RADC	$5,851,000	
Avionics Lab.	2,745,000	
ESD	1,167,000	
BSD	1,071,000	
SSD	1,059,000	
ASD	753,000	
ARPA		4,923,000
DASA		3,506,000
NASA		1,119,000
AFLC		200,000
Navy		170,000
AEC		102,000
Army		80,000
NSF		80,000
NSA		75,000
ADC		24,000
TOTAL		$66,778,000

TABLE 2
SOURCES OF FY-1965 FUNDS

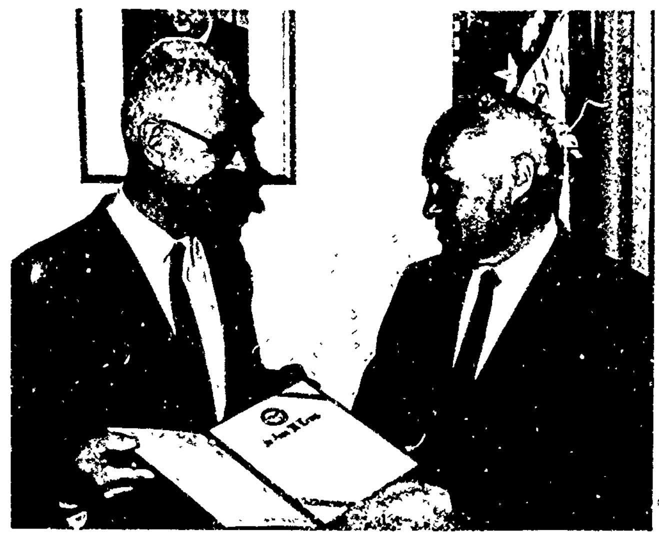
OAR		$41,006,000
AFSC		9,491,000
R & T Div.	$4,419,000	
Avionics Lab.	2,750,000	
RADC	1,040,000	
ESD	1,030,000	
SSD	232,000	
BSD	20,000	
ARPA		3,483,000
DASA		2,980,000
NASA		655,000
AFLC		200,000
NSA		200,000
NSF		80,000
Army		80,000
ADC		41,000
TOTAL		$58,216,000

sion and the various laboratories of this Division. What this means is that while the programs remain at AFCRL, the R & T Division and its laboratories will have direct management responsibility for them, and will set the level of support for each. The purpose of this administrative change is to improve coupling between Air Force research and development agencies, and thus the coupling between AFCRL and the operational Air Force.

CONTRACT PROGRAM: The bulk of the AFCRL budget — about 70 percent — is expended on contract support. The total number of outstanding contracts changes from month to month but averages about 975. Taking 1 April 1965 as a reference date, it is seen that on that date AFCRL had 939 outstanding contracts. Of these, 400 were with U. S. industrial concerns, 299 were with U. S. universities, 89 were with foreign universities, and companies, and the remainder were with research foundations, with other Government agencies (transfer of funds) and for special procurement actions.

The wide use of contracts in conducting an in-house program may seem an inherent contradiction. As such, the matter requires clarification because it may lead to some confusion among those whose familiarity with Government research procurement procedures extends only to those agencies that rely wholly or in large part on contracts for accomplishing their missions.

As was pointed out earlier in this chapter, AFCRL is defined as an in-house laboratory because it is the AFCRL scientist and engineer who plan the research, initiate a line of inquiry, organize the program, interpret the results and share the workload of actual research. AFCRL's contracts are in general contracts for work that is in direct support of research carried out within the AFCRL laboratory. Almost always the contracts are managed by AFCRL scientists who are themselves active, participating researchers. AFCRL does not use contracts as the primary means for purchasing scientific talent and judgment.



Dr. John Evans, Director of AFCRL's Sacramento Peak Observatory, receives the Distinguished Civilian Service Award from Air Force Secretary Eugene Zuckert, the highest award made to DoD civilian employees. In both 1964 and 1965, AFCRL scientists received this honor. The 1964 award was made to Dr. Norman W. Rosenberg.

This matter is reemphasized in order that the extremely broad program covered in this report can be understood in relation to the relatively small number of persons comprising AFCRL. The contract program tends to free the AFCRL scientist from much that is routine in science and to increase his productivity.

There is another role that the contracts play in the AFCRL program.

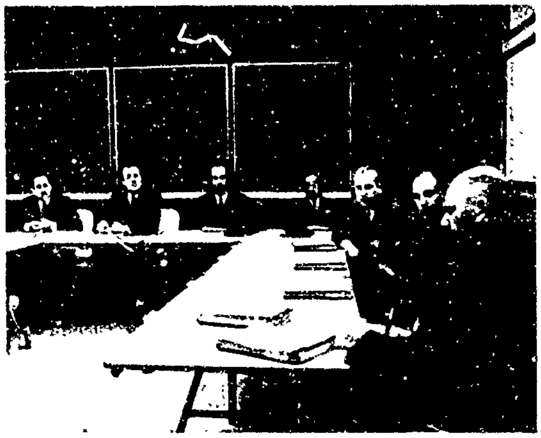
This role relates to responses to Air Force operational problems when the competence exists in AFCRL for dealing with such problems. No research laboratory, because of the need for continuity and stability, can transfer people, money and facilities to handle each technical problem in urgent need of solution. AFCRL, however, maintains a reservoir of scientific competence capable of outlining approaches for the solution of problems and identifying sources of contract talent that can be drawn upon to develop the equipments or systems needed. When the Air Force comes to AFCRL with unexpected technical problems demanding solution, AFCRL in such cases often relies heavily upon contractors. Contracts can serve as a cushion against the impact of such Air Force requests for immediate assistance, permitting the main stream of laboratory research to continue largely uninfluenced.

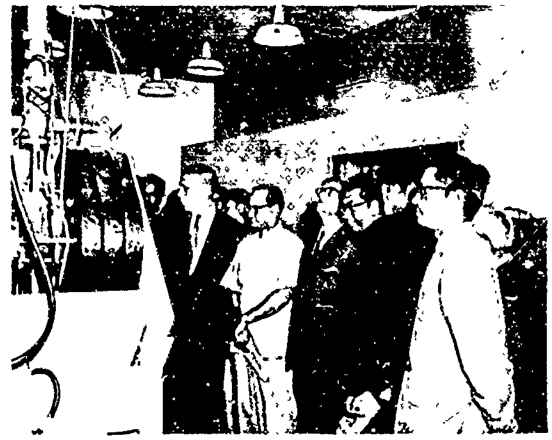
In this report, emphasis is placed on the contributions of AFCRL scientists, rather than the contributions of scientists in other laboratories working under AFCRL contract. The achievements of scientists working under AFCRL contract should more properly be announced and discussed by those scientists themselves or by the institutions with which they are affiliated. For these achievements, credit can be reflected on AFCRL only insofar as a judicious application of the contract budget was made. If the programs discussed in this report fail to reflect the many outstanding contributions made during the period by scientists under the AFCRL contract program, it is for this reason.

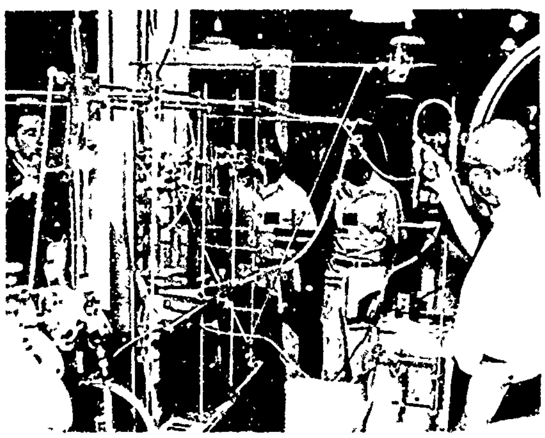
FACILITIES AND EQUIPMENT: The main laboratory buildings of AFCRL are located at L. G. Hanscom Field. Hanscom Field stretches across parts of four Massachusetts communities at a point about 20 miles west of Boston. These communities are Bedford, Concord, Lexington and Lincoln. AFCRL is one of three major research and development organizations located on Hanscom Field. The other two are MIT's Lincoln Laboratory, less than a quarter mile distance from AFCRL, and the Electronic Systems Division (ESD) of the Air Force Systems Command, which is the largest of the three organizations.

Immediately outside the limits of Hanscom Field is the MITRE Corporation, a not-for-profit R & D organization set up to assist ESD in its various system development programs. Hanscom Field itself is located just off Route 128 along which a substantial part of the nation's total electronics and industrial research capability is located.

About 900 of AFCRL's 1100 employees are physically located at Hanscom Field. The remainder are located at AFCRL's many permanent field sites which literally stretch from coast to coast. Most of the permanent AFCRL sites are located within a radius of 60 miles or so from Hanscom Field. The largest of these sites is the Sagamore Hill Radio Observatory in Hamilton, Mass., where are located two large radio telescopes, one with a dish 84 feet in diameter, the other with a dish of 150 feet. Another large off base site is AFCRL's weather radar research facility in Sudbury, Mass. Other sites in the Massachusetts area are used to make antenna pattern measurements, for detecting worldwide sferics (lightning strokes) activity, for monitoring geomagnetic variations, and for propagation research.



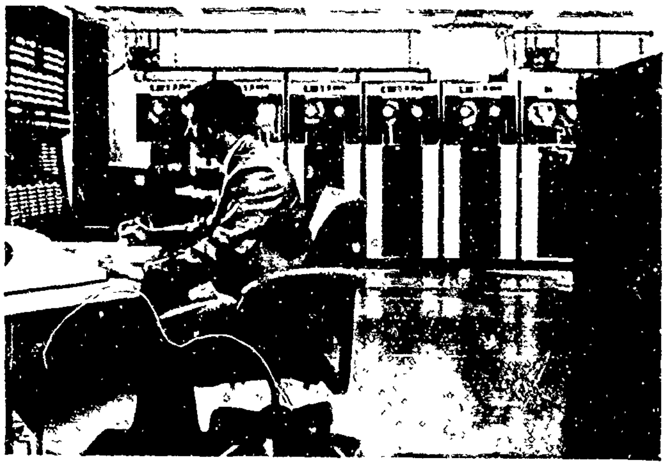




Several hundred visitors to AFCRL each year meet with AFCRL scientists and tour AFCRL research facilities. In the upper left photograph, AFCRL Vice Commander Colonel James L. Dick meets with a delegation of Argentine Air Force officers. In upper right, Indian journalists visit AFCRL's radiation research facilities. In lower left, young officers from Wright-Patterson AFB observe equipments used in ultrapurification of materials. In lower right, two science teachers from a local school learn of methods for growing single crystals.

AFCRL's largest single off-base installation is the Sacramento Peak Observatory in Sunspot, New Mexico, one of the finest solar observatories in the world. The Sacramento Peak Observatory, in turn, wholly supports the solar radio observatory at Fort Davis, Texas, operated by the Harvard College Observatory. Since the late 1950's AFCRL has operated a site at Thule, Greenland, for observing the aurora, magnetic activity and airglow. Permanent AFCRL balloon launch facilities are located at Holloman AFB, New Mexico, and Chico, California.

A new field site was established during the period at NASA's rocket range at Wallops Island, Virginia. This site, previously operated by the Lincoln Laboratory, will be used by AFCRL's Meteorology Laboratory to observe, by means of radar, atmospheric conditions associated with clear air turbulence.



An IBM 7044-1460 general purpose computer was installed during the reporting period. In the past, most of AFCRL's general computational requirements were met under contract.

The research programs of AFCRL entail the continual acquisition and disposition of temporary field sites — the negotiation with New Zealand for an observing site in the Cook Island group for viewing the 30 May 1965 eclipse, the lease of five square miles of flat Kansas wheat land for a month-long series of microscale meteorological observations, and the transfer of a dust-free trailer to northern Sweden used for the assembly of rocket nose cones to be used in noctilucent cloud experiments. Other foreign sites (acquisition of which often requires lengthy negotiation and involves State Department assistance) acquired for special projects were in Malta, Thessalonika, Greece, Grand Bahama Islands, Barbados and Okinawa. During the two-year period, AFCRL programs were carried out in more than 100 field sites all over the world.

Installed within AFCRL's main laboratory facilities at Hanscom during the period were four major research equipments. The largest of these was a new IBM 7044-1460 general purpose digital computer. The need for such a computer has existed for many years, during which time AFCRL was forced to buy time on the Lincoln Laboratory and Mitre computers, as well as to contract for computer services. Other equipments installed were a 6.6 meter vacuum spectrograph, the most sensitive instrument of its kind in the world, a 21 mev linear accelerator for research on radiation damage to electronic materials, and a large data processor for decommutating environmental data from various AFCRL satellite and rocket sensors in connection with AFCRL's new space environment forecasting program.

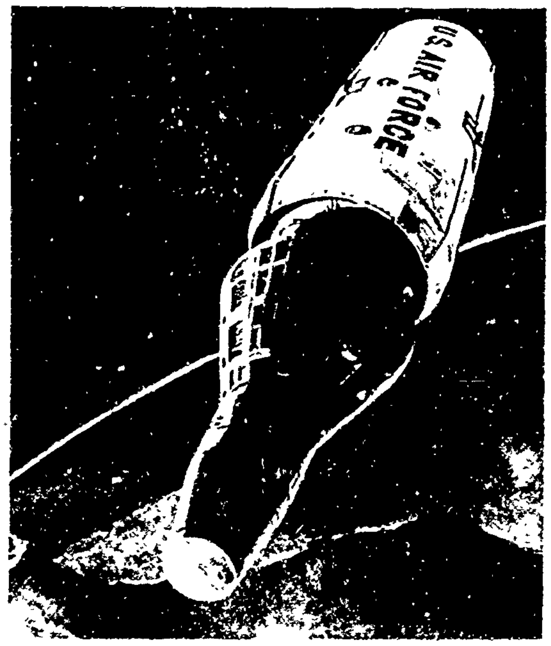
ROCKETS, SATELLITES AND AIRCRAFT: During the two-year reporting period, July 1963 - June 1965, AFCRL launched 104 large sounding rockets and designed scientific instrument packages which were placed in orbit aboard nine Air Force and NASA satellites.

Of the 104 rockets, 84 were launched by just one AFCRL laboratory — the Upper Atmosphere Physics Laboratory. In addition to the 84 rockets, the Upper Atmosphere Physics Laboratory designed packages for three satellites. The Space Physics Laboratory launched 15 sounding rockets and had experiments aboard five satellites during the period.

More than one-third of the rockets — 39 — were launched from the Air Proving Ground Command at Eglin AFB, Florida. Twenty-two were launched from the White Sands Missile Range, New Mexico, and ten from Fort Churchill, Canada. Six rockets were launched from aboard an aircraft carrier off the coast of Peru near the equator.

Rockets launched during this period examined almost every aspect of the earth's upper atmosphere and near-space environment. The largest programs can be grouped under certain broad categories — atmospheric winds, temperatures and densities, the electrical structure of the ionosphere, solar ultraviolet radiation, atmospheric composition, the earth's radiation belts, cosmic ray activity, airglow and the aurora.

Since AFCRL launched its first rocket in August 1946 — an early V-2 — the laboratories had launched a total of 554 rockets as of 30 June 1965.



AFCRL has proposed some 25 experiments, most of them involving optical and infrared radiation, to be conducted by astronauts in the Air Force's Manned Orbiting Laboratory.

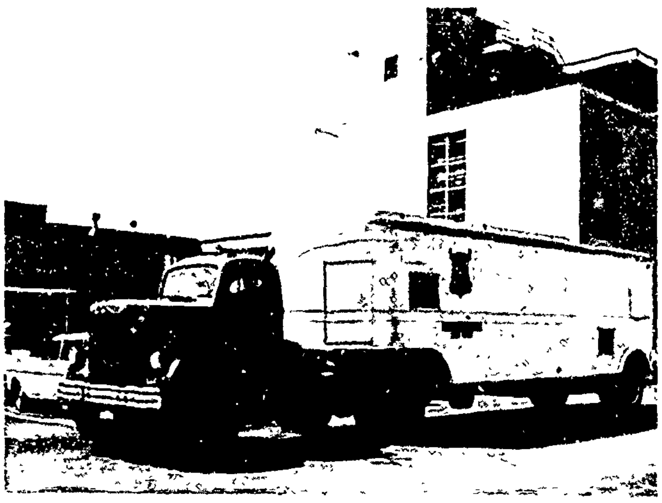
This figure, which does not include an even larger number of smaller meteorological rockets, is the largest number of sounding rockets launched by any group or laboratory in the country and, by safe inference, in the world. The AFCRL program has given scientists all over the world their most detailed picture of the earth's dynamic environment.

The first U. S. satellite, 1958 Alpha, launched in January 1958, carried an AFCRL experiment — a microphone-type micrometeorite detector. Since then, AFCRL scientists have had one or more experiments aboard scores of Air Force and NASA satellites — some of these entirely devoted to AFCRL experiments.

Plans for expanded satellite programs got underway during the period and this planning will be reflected in future AFCRL reports. Two of these programs are particularly noteworthy. First, AFCRL designed a series of experiments for the Gemini 5 and 7 programs involving the measurement of optical and infrared radiation from stars, the earth and missile launches. Second, AFCRL has proposed a series of 25 experiments — experiments growing out of research conducted by AFCRL's Optical Physics, Upper Atmosphere Physics and Space Physics Laboratories — for the Air Force's Manned Orbiting Laboratory program.

AFCRL has two KC-135's used for continuing programs in gravity research and ionospheric and optical physics, and three C-130 flying laboratories instrumented to make gravity measurements, for cloud physics research and for the measurement of atmospheric visibility. A U-2 aircraft is used for a host of meteorological measurements where it is necessary to observe weather patterns from extreme altitudes.

LOGISTICS SUPPORT: The dynamics of a large research laboratory are best highlighted by the indirect means of reviewing the logistics support and housekeeping services needed to keep the laboratory functioning. For example, during the two-year period of this report, AFCRL logistics personnel processed more than 35,000 cash and blanket order purchases, purchases usually involving small off-the-shelf electronics items. The office handled



Observational sciences, by their very nature, give rise to a heavy logistics workload. Here a trailer, tightly sealed and with a large air filter system, is leaving AFCRL for shipment to Sweden where it will provide a dust-free evironment for the assembly of rocket nose cones.

about 8,000 purchase requests for larger items and processed an equal number of orders for items procured through Government sources of supply.

AFCRL support personnel were responsible for general data processing by AFCRL scientists, and often for the decommutation of telemetry data from rockets and satellites. Research involves an inordinately large publication effort. The Laboratory distributed (average distribution, 500 copies) more than 200 in-house reports and almost 1000 contractor reports during the period. Procedures were also worked out for the selected dissemination of certain reports to those laboratories and agencies having direct interest in their content.

Other in-house services include the electrical engineering involved in the design and fabrication of printed circuit boards for laboratory scientists, the fabrication of rocket and satellite instrumentation, and the engineering design of certain equipments. An example of the last was a shipboard balloon launcher, discussed in Chapter X, which w .s designed and built by the AFCRL engineering staff.

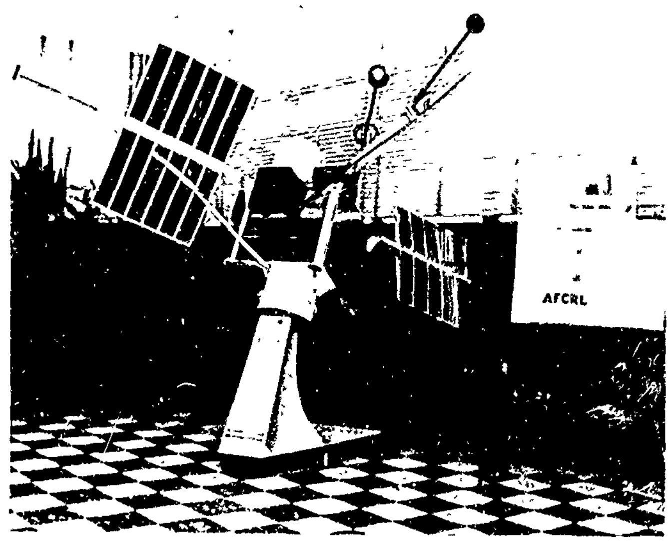
The service function in which AFCRL takes most pride, however, is its library. This library has grown into one of the finest research libraries in the world. Its geophysics collection is unexcelled. During the period, it acquired more than 15,000 new monographs alone, in addition to large serial and technical report acquisitions.

Visitors to the AFCRL library are most impressed by the library's historical collection. For example, the library has complete collections of the *Philosophical Transactions of the Royal Society of London* dating back to 1665, the *Histoire of the Paris Academy* dating back to 1699, and the *Commentarii of the Russian Academy of Science* dating back to 1726. In addition, the library has acquired a large collection of original notebooks of the third and fourth Lords Rayleigh as well as nearly all of the manuscript material of both Lords Rayleigh. These papers are being copied and made available to other libraries and, following cataloging will be published by a commercial publishing firm.

The library also has an exceptionally large collection of translations. Many of these translations were made for AFCRL scientists by library personnel or under library contract. Scientific journals of Bulgaria, China, Czechoslovakia, Holland, France, Germany, Greece, Hungary, Italy, Japan, Poland, Russia and Sweden are all represented in this translation series. During the period, the library built its collection of Chinese science journals and monographs into one of the most comprehensive in the U. S. The tables of contents and abstracts of articles from these Chinese journals are circulated to other laboratories throughout the country, and provide one of the best sources of information on the status of Chinese science.

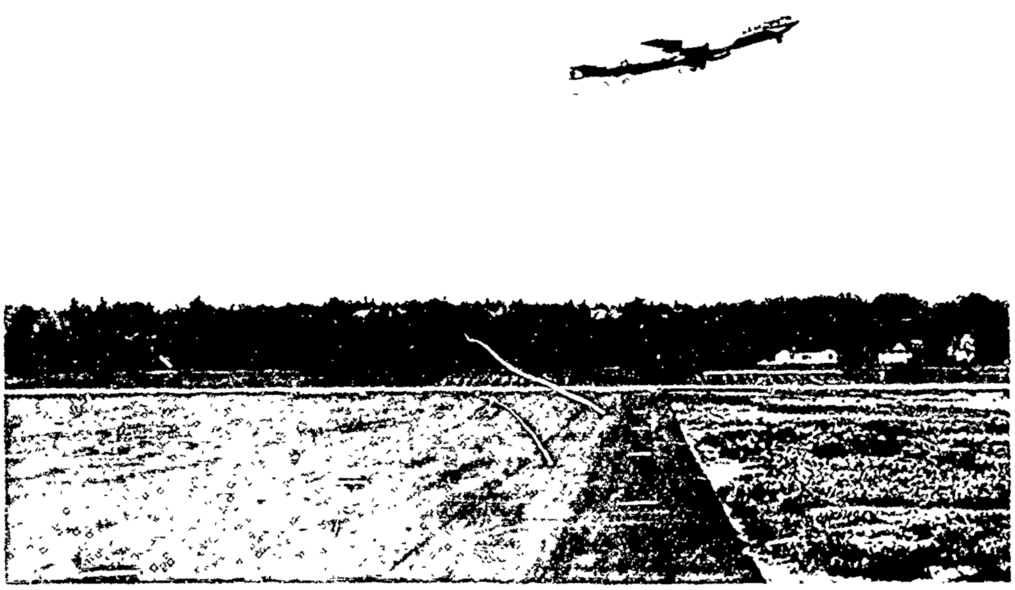
SUMMARY: The above paragraphs are intended to provide a few administrative points of reference to the research program of AFCRL covered in the following chapters of this report. Another point of reference should be noted.

The chapters of this report are organized by laboratory, and these laboratories, in turn, as was noted, are organized along disciplinary lines. But classification of scientific work (the first step in its organization), as all those engaged in this work know, is often artificial and arbitrary. Classification is simply the essential means for coping with things, for integrating the infinite multiplicity of phenomena into units that can be grasped and understood. While the systematic investigation of small isolated entities is an indispensable procedure of science, this procedure nevertheless conflicts with the fundamental goal of science which is to synthesize its myriad concepts and laws into unifying elements — which is another way of saying that the goal is more economical descriptions of physical phenomena.



AFCRL is making increasing use of satellites in its research program. Here a model of the OV2 series of satellites is displayed in the AFCRL lobby prior to shipment to the Paris Air Show held in the spring of 1965.

For the research manager attempting to keep segments of research neatly compartmentalized, the tendencies toward greater unity result in a spreading out of the research beyond the compartment boundaries (plasmas are discussed in different contexts throughout this report, for example), and is thus a continuous source of concern. Perhaps this concern is ill-founded, because departures from neat compartmentalizations are really measures of growth and vitality.



The Laboratory's ionospheric flying laboratory leaves from Hanscom Field for the Pacific to observe the 30 May 1965 eclipse.

II Upper Atmosphere Physics Laboratory

The Upper Atmosphere Physics Laboratory is concerned with the one percent of the earth's atmosphere that extends from the lowest level of the ionosphere — the D layer at about 50 km — out to the magnetopause, the boundary of the earth's magnetic field, 70,000 km or more.

Within this one percent of the atmosphere there occurs the dramatic but dimly understood physical and chemical processes that moderate the environment at the surface of the earth. The protective blanket of the upper atmosphere protects life from the harmful effects of the solar ultraviolet and cosmic radiation, and profoundly influences the operation of the earth's giant meteorological engine.

The free electrons and ions found throughout this region specify the performance capability of most radio communications and govern the parameters of surveillance radars. The visible emissions over the sky at night resulting from the recombination of atoms and molecules set the threshold of sensitivity for optical reconnaissance equipment. And the densities and temperatures of this region are factors in the design of aerospace vehicles.

Upper atmosphere research is comprised of a diversity of studies. The Laboratory is concerned with upper atmosphere densities, pressures and temperatures, with airglow and the aurora, with the physical and electrical structure of the ionosphere, with the chemical processes of the ionosphere, and with ionospheric and geomagnetic effects on radio propagation. Last, the

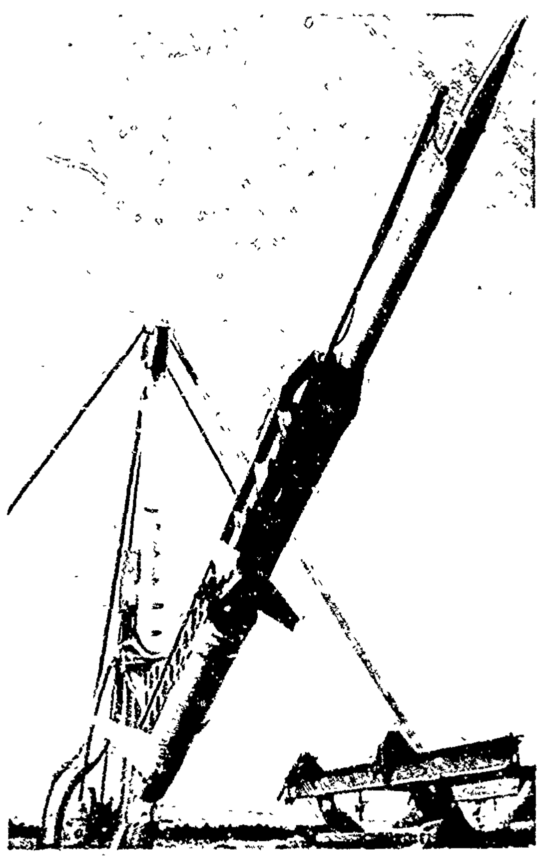
Laboratory is concerned with ultraviolet radiation, the fundamental source of energy that maintains the dynamic processes of the upper atmosphere.

The Laboratory is AFCRL's largest user of sounding rockets and satellites. During the two-year period, the Laboratory launched 84 large sounding rockets. Because the properties of the upper atmosphere vary widely with latitude, the Laboratory has established a number of field sites and data gathering sites all over the world — some operated by AFCRL personnel, but most operated by contractors. The Laboratory also flies what is perhaps the most completely equipped aircraft (a KC-135) in the country for recording ionospheric characteristics.

(Other AFCRL Laboratories conducting research related to that of the Upper Atmosphere Physics Laboratory are the Space Physics Laboratory, Chapter IV, the Optical Physics Laboratory, Chapter VI, and the Aerospace Instrumentation Laboratory, Chapter X.)

ATMOSPHERIC WINDS, DENSITIES AND TEMPERATURES

The most direct and effective way to obtain a profile of winds, densities and temperatures in the region between 50 to 700 km is by sending rockets with various types of sensors through a vertical cross-section of this altitude regime. Features of this profile are under continuous revision as more data are accrued. One familiar description of the profile is the plot of temperature as a function of altitude. In this plot, a characteristic bulge is seen at an altitude of about 50 km, at the stratosphere-mesosphere interface, denoting a temperature maximum. Temperatures then decrease sharply up to about 100 km. They rise steadily again to around 1200 degrees K at around 700 km. The plot usually terminates with the dashed line of extrapolation.



The Upper Atmosphere Physics Laboratory is the largest AFCRL user of sounding rockets. From July 1963 to June 1965, Laboratory scientists instrumented 84 large sounding rockets for a variety of observations. The Exos rocket is shown here.

Temperature and density are somewhat correlated parameters. One can often be derived from the other. Also, from a knowledge of temperature and densities, it is possible to derive certain information about the chemistry of the upper atmosphere and energy transport processes. These temperature variations are largely the result of chemical changes which create at various levels heat sinks and heat sources. But not enough is known of the physics and chemistry of the upper atmosphere to formulate an equation giving results that agree with measurements.

The chemistry of the upper atmosphere, as well as investigations of the solar ultraviolet radiation which set in motion the chemical processes, are dealt with in separate sections of this chapter.

Data from the many AFCRL experiments conducted during the period were incorporated in the "Supplemental Atmosphere to the Standard Atmosphere," a compilation of commonly agreed upon values of temperatures, densities, and pressures. The Supplemental Atmosphere covers the altitude region of 90 to 700 km, and was compiled by a task group of representatives from several outside laboratories under the chairmanship of an AFCRL scientist. The Supplement augments data incorporated in the "US Standard Atmosphere, 1962." Data for the Supplemental Atmosphere came from many sources, but a major contribution was made by AFCRL through its large rocket probe program for measuring upper atmosphere environment.

SOUND AND TEMPERATURE: One of the first things learned in high school physics is that the velocity of sound varies with atmospheric temperature. The Laboratory has applied this principle to atmospheric temperature measurement. Such measurements — consisting of a detonation at altitude and an acoustic detector on the ground — have, in fact, provided the most reliable estimates of ambient temperatures at altitudes up to 85 km. But ground-based acoustic detection of detonations taking place at altitudes above 85 km requires extremely large explosive charges. For example, more than 200 pounds of explosives are needed for ground-based acoustic detection of detonations at altitudes above 150 km.

An alternative technique for recording acoustic pulses of high detonations has been demonstrated by the Laboratory. The technique involves optical — that is, photographic — means to record acoustic wave propagation. The experiment used to demonstrate the technique was carried out at an altitude of 108 km above Eglin AFB, Florida. A glowing chemical trail is released by the rocket and an explosive charge (of about 14 pounds) from the same rocket is detonated in or near the trail. The detonation imposes a visible pressure pulse on the chemical trail. The gas used for the chemical trail was a mixture of triethyl aluminum and trimethyl aluminum. The gas glows for a minute or so following release with an intensity sufficient to permit photography.

Two types of photographic records were obtained — a framed movie sequence, and a streak photograph. The streak photograph record proved to be more valuable. Interpretation of the lines of enhanced luminosity on the chemical trail (representing the shock waves) is an involved mathematical process. To be calculated are the rapid expansion of the gas cloud, ratio of specific heats, molecular weights, and so on. At an altitude of 108 km, an acoustic velocity of 0.35 km per second corresponds to a temperature of 300 degrees K, plus or minus 50 degrees. This figure, which was derived on the basis of the photographic record of the experiment, compares to the value of 250 degrees K given in the US Standard Atmosphere.

Release of chemicals in the upper atmosphere is referred to throughout this chapter. Here is clearly seen the helical configuration that results because of change in wind direction with altitude. Densities, atmospheric chemical reactions, and ionospheric disturbances can all be studied by means of chemical releases.

UPPER ATMOSPHERE WIND PATTERNS: The chemical trail technique was also used during the period to measure nighttime wind patterns in the upper atmosphere. In a series of rocket flights launched from Eglin AFB, Florida, the chemical release trail (trimethyl aluminum which remains visible for five to eight minutes) was started at an altitude of about 90 km and continued until the rocket reached 150 to 160 km. A vertical trail 60 km long was thus created in the nighttime sky.

These experiments uncovered an unsuspected and surprising regularity in the wind velocity and direction of upper atmosphere winds. Winds with velocities of 100 to 150 miles an hour immediately distort this trail, forcing it in some places to the left of the center line of flight, and in other places to the right. But casual observation shows that these distortions are not random. The trail, as seen two dimensionally from the side, describes a sine wave. Actually, the trail assumes the configuration of a helix.

The forces creating this pattern are fairly easy to decipher. Winds simply change direction with altitude. Viewed from above, this directional change is clockwise. Thus, at 100 km winds may be from the east, at 110 km they may be from the south, at 120 km from the west, and at 130 km from the north. The result is that the luminescent trail takes on a helix configuration.

This describes the situation for a single observation. But what happens to the upper atmosphere winds at a particular altitude at different times during the night? The rocket firings were spaced at intervals throughout the night in order to observe possible changes at a given altitude. It was found that at a given altitude the wind direction changes in a clockwise manner 360 degrees during a 12-hour night. At lower altitudes this rotation is somewhat more; it is less at higher altitudes.

This means that the helix configuration assumed by the chemiluminescent trail is rotating. Observing this helix from the side in a two-dimensional plane (where it is then seen as a kind of sine wave), we see that the wave moves downward about one wavelength during a 12-hour period.

The measurements giving rise to this picture of upper atmosphere winds were carried out during the night when solar influences were at a minimum. To determine seasonal variations in wind patterns, two series of measurements were made — the first in the winter, the second in the spring. The only seasonal variation noted was that the north-south wind velocities were greater in the winter than in the spring.

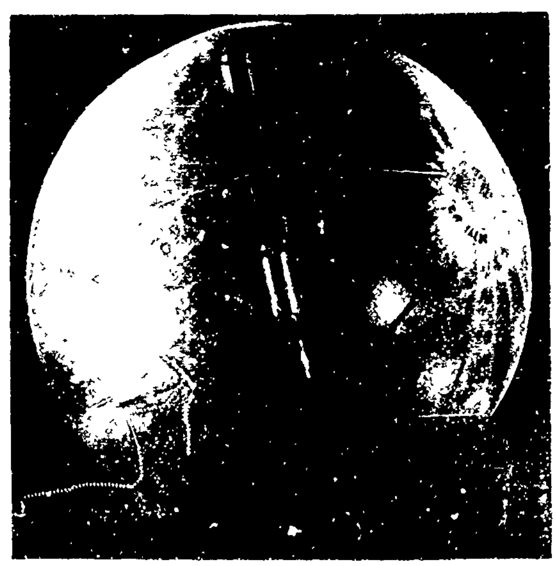
TECHNIQUES FOR DERIVING DENSITY DATA: Four techniques were used by the Laboratory for the direct measurement of upper atmosphere densities. These techniques involve a free-falling metal sphere, the Brehmsstrahlung effect, ionization gauges, and calculations of satellite drag.

The falling-sphere technique is used for measuring densities at altitudes below about 120 km. The technique consists of ejecting a seven-inch diameter rigid sphere from a rocket. The sphere contains an omnidirectional accelerometer that senses atmospheric drag forces. During the reporting period, this technique was used in nine rocket flights (Nike Cajuns and Nike Apaches) — six from White Sands, New Mexico, under funding by the Army in connection with the Army's reentry program, and three from Eglin AFB, Florida. A new accelerometer was introduced for some of the later flights. With a sensitivity of 5×10^{-5} g, this new accelerometer extends the altitude at which this technique can be used to about 120 km.

The Brehmsstrahlung technique will be first applied to measurements of atmospheric densities in a rocket flight scheduled for late 1965. The technique consists of firing a beam of five kev electrons from an electron gun into the surrounding atmosphere. These electrons interact with the atoms of the atmosphere and the Brehmsstrahlung radiation produced is measured by an x-ray detector in the rocket. Calculations of expected x-radiation between the altitudes of 90 to 200 km were made in a Laboratory vacuum chamber.

Ionization gauges measure atmospheric density by first ionizing the atmospheric gas. A voltage is set up between two terminals. The rate of current flow in the ionized gas between the terminals is a measure of the atmospheric density. During the period, the Laboratory designed, constructed and tested a warm-filament type ionization gauge for installation in the Air Force OV-2 satellite scheduled for launch in the summer of 1965. Three ionization gauges of the cold-cathode magnetron type were incorporated into a Blue Scout satellite launched from Wallops Island in the spring of 1965. Both the warm-filament and the cold-cathode gauges were calibrated by AFCRL scientists down to a pressure of 10^{-9} torr.

A final study of atmospheric densities involved drag calculations of the Explorer XVII satellite. A Baker-Nunn



Free-falling balloons containing highly sensitive accelerometers are used to measure atmospheric densities. The three foot diameter balloons are carried aloft by rockets. This technique was greatly refined during the period with improved balloon and accelerometer design.

Laboratory vacuum chamber is used to calibrate instrument for measuring atmospheric density. Instrument being tested is based on Brehmsstrahlung technique in which atmospheric gas is bombarded with electrons producing x-radiation.

camera provided the basic observational data. For this study, the Laboratory developed a new differential orbit correction program. Variations of density with the solar flux, perigee height, angle between perigee and the center of the diurnal bulge and the geomagnetic index were all taken into account in these calculations. Agreement between experimental data and theoretical models was within 25 percent.

PHYSICAL CHEMISTRY OF THE ATMOSPHERE

This section deals with the electrons, atoms, ions and molecules of the upper atmosphere, and with their interactions and transformations. Transformation is in fact the characteristic attribute of the gases comprising the upper atmosphere — a continuous, kaleidoscopic pattern of dissociation, attachment, and recombination. This process is maintained by collisions between atmospheric species and by interaction with the radiative energy of the sun — primarily ultraviolet radiation. Products of these collisions and interactions are the ionosphere, airglow and the aurora.

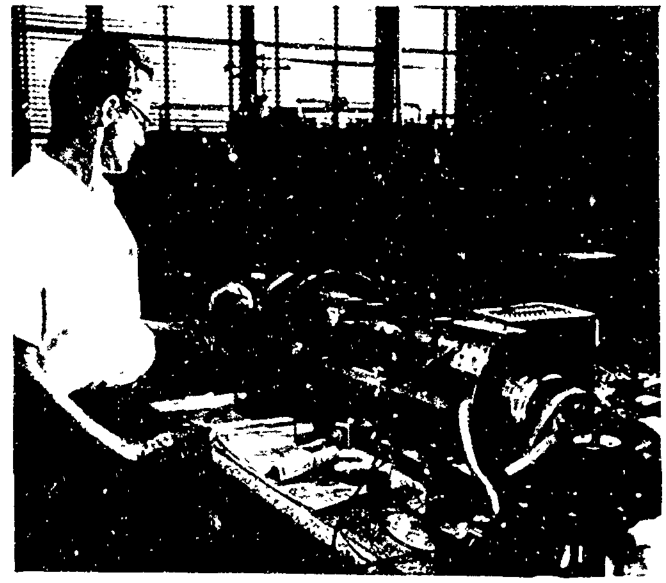
The physical chemistry of the atmosphere has many parts. The exigencies of the research situation forces the researcher to look at each part separately. Although the parts discussed in this section are treated as somewhat discrete areas of investigation, their interrelationships when viewed from a more distant perspective become starkly visible.

Nor does one see this unity only among the projects discussed in this section on physical chemistry. The foregoing discussion of temperature and densities is highly related. One cannot understand the rates of chemical reactions unless one knows something of the mean free paths, which is another way of describing atmospheric density. Measurements of atmospheric temperature, also discussed earlier, can tell the researcher much about chemical processes producing temperature variations, and temperature itself affects reaction rates. Also intrinsically related to physical chemistry processes of the upper atmosphere is the work on ultraviolet radiation and ultraviolet spectroscopy covered later in this chapter.

Scores of techniques are used to measure upper atmosphere processes. These techniques are the basis for instrumentation sent aloft in rockets and satellites. The three effects of physical chemistry processes of primary interest to the Air Force are absorption, emission and attenuation of electromagnetic radiation. These effects set the limits to the efficiency of reconnaissance and surveillance equipments. The scientist, however, is interested in understanding basic mechanisms that permit him to predict effects. The AFCRL program couples these two interests.

ATMOSPHERIC COMPOSITION: The study of the physical chemistry of the upper atmosphere must necessarily begin with knowledge of the relative concentrations of atoms, ions and molecules at different altitude levels. The most precise, direct and effective way to measure the neutral and charged particle composition of the upper atmosphere is by placing a mass spectrometer in a balloon, rocket or satellite. During the two years covered in this report, a variety of mass spectrometer systems were flown on balloons to measure the neutral composition from ground level to 30 km, on Nike Cajun rockets to measure the neutral and ionic constituents from 50 to 115 km, and on Aerobee Hi rockets to measure the neutral composition from 110 to 230 km.

Determination of certain minor constituents in the lower atmosphere would aid greatly in understanding the thermodynamic and chemical processes within the lower atmosphere. A mass spectrometer with a sensitivity of at least one part per million is needed to detect some of these constituents. A time-of-flight mass spectrometer system with a sensitivity of one part per million for helium was developed by AFCRL and the Bendix Corporation. Three balloon flights were made in September 1963 to check out the instrumentation. The mass spectrum was scanned from one atomic mass unit to approximately 50 AMU while at the same time the gases He, N_2, O_2, A, and



Mass spectrometer to be flown on Aerobee 150 is checked out in the laboratory. This particular spectrometer was flown on 21 July 1965 from White Sands to measure ion composition above 120 km.

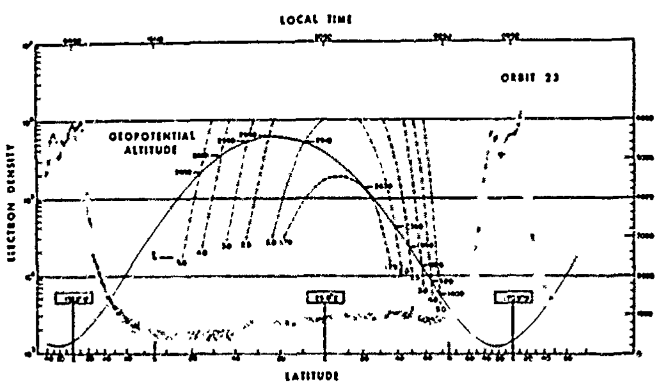
CO_2 were continuously monitored. The data indicate these constituents remain in constant ratios (within a small instrument error) up to balloon peak altitude of 90,000 feet.

A unique quadrupole mass spectrometer system using a liquid nitrogen cooled zeolite pump was developed for measuring both the ion and neutral composition of the D-region (50 to 90 km). In the past, no comprehensive measurements of this type were performed in the D-region because of a number of extremely difficult sampling problems associated with the relatively high atmospheric pressures in the D-region and aerodynamic and plasma interference by the rocket. On 31 October 1963, and 11 March 1964, these quadrupole systems were flown on Nike Cajun rockets. Measurements of positive ion composition in the D- and lower E-region were made for the first time.

The results were startling and unexpected. The total concentration of NO^+, O_2^+ and N_2^+ ions in the D-region comprised only 16 percent of the total ions rather than 100 percent as theoretically predicted. The largest amount of the ionization in the D-region was found to be due to "cluster" ions of high atomic mass. Further, within the lower E-region two stratified distinct layers of metallic ions of probable meteoric origin were detected. It is believed that these metallic ions are responsible for the maintenance of the nighttime E-region.

On September 1963 a time-of-flight mass spectrometer system was successfully flown on an Aerobee Hi rocket to measure neutral composition from 110 to 230 km. Good data were obtained on N_2, O_2, and O number densities.

Concurrent with the in situ experimental measurements program, Laboratory scientists developed inhouse for JPL-NASA a small quadrupole mass spectrometer system for use on a Mariner probe to sample the atmosphere of Mars. This system, although in prototype stage weighs five pounds, consumes seven watts and occupies approximately 3200 cubic centimeters. It is capable of making accurate, analytical measurements of the composition of the Martian atmosphere. The system was delivered in January 1964 to JPL for extensive testing and evaluation. The earliest scheduled date for a Mariner probe with this type of instrument aboard is 1969.



Variation in electron density with altitude is quite evident below the F-layer. Plot shows a slight increase in the electron density when the satellite was at apogee due to latitude variations. Differences in structure of the two electron density peaks were caused by satellite tumbling.

CHARGE EXCHANGE AND ION-MOLECULE REACTIONS: The physical chemistry of the upper atmosphere is essentially a story of charge exchange and ion-molecule reactions. The two terms should be explained. Charge exchange simply means the transfer of one or more electrons — in its simplest form a recombination of a free electron with an ion (in which case a quantum of energy is released). Or it can consist of the recombination of an electron with an ion molecule and the resulting dissociation of the ion molecule into two neutral species. Ion-molecule reaction refers to a process in which a charged or uncharged atomic or molecular species is transferred between ionic and neutral reactants. The transfer can be affected by a photon, an electron, or a larger species. The result is the formation of new chemical bonds.

Scientists studying these processes are concerned for the most part with a single parameter — with the cross section, or the rate of reaction. The problem is that cross sections are different for different constituents of the earth's atmosphere. Also a given atmospheric species may be affected only by a photon of a given energy — or put another way, by certain solar UV wavelengths. Only within the past decade, with highly sensitive instrumentation, has it been possible to study the various reactions.

During the reporting period, AFCRL investigated a large number of upper atmosphere reactions. Only one, by way of example, will be covered here. This was a study of low energy (0.2-20 ev) collision processes occurring in carbon dioxide (CO_2). This study led to observations of the production of ionic species O_2+, C_2O_2+, CO_3+, C_2O_3+, and C_2O_4+.

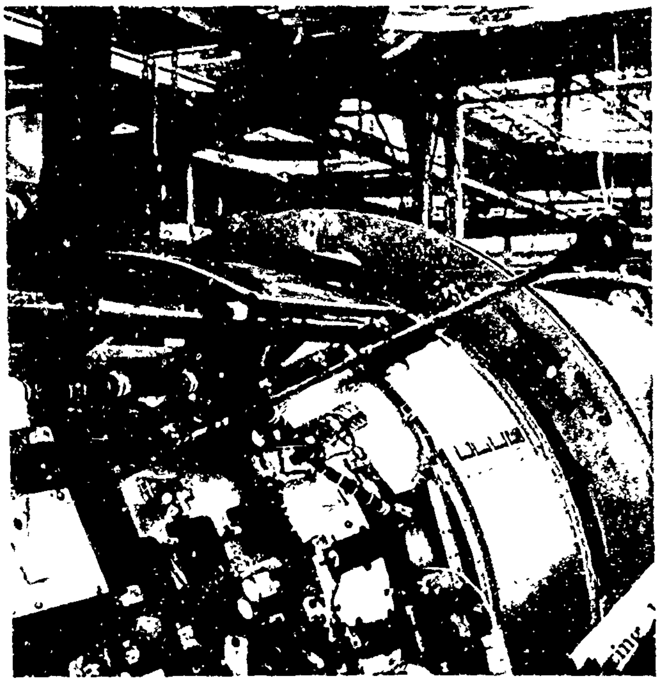
The O+ fragment ions from CO_2 appear to be the reactant species responsible for the production of O_2+. Either highly excited neutral levels of CO_2 or short-lived excited states of CO_2+ react with neutral CO_2, leading to the production of C_2O_2+, CO_3+, and C_2O_3+. The ion C_2O_4+ is produced in a collision between CO_2+ in the ground state and two molecules of neutral CO_2. The reaction rate coefficient for this three-body process is about 3×10^{-28} $cm^6\ sec^{-1}$ for reactant ions of average energy 1 ev.

Preliminary studies using isotopically labeled oxygen on the reaction $O+ + O_2 \longrightarrow O_2+ + O$, a process of great interest in the dynamics of the ionosphere, have shown that, contrary to the usual assumptions, this process occurs only in part by simple electron transfer. The remaining contribution at low energy is an ion-atom interchange reaction. Each mechanism contributes approximately 50 percent of the observed product.

Measurements of cross sections for ionization of atmospheric gases by electron bombardment have led to results which are in excellent agreement with the most recently reported data of other workers. The simple and rapid measuring techniques used here appear to be sufficiently reliable for precise measurements on other species for which there are serious disparities in the published ionization cross sections.

ELECTRICAL STRUCTURE: When one speaks of the electrical structure of the atmosphere, one is speaking of the ionosphere. But when viewed as a property of the upper atmosphere, electrical structure becomes a property inextricably tied to the physical chemistry of the atmosphere. The AFCRL study of electrical structures therefore falls logically within the context of the above discussion of charge exchange. Work under this category deals with the investigation of the temperature and densities of electrons and positive and negative ions — the measurement of these charged species at altitudes from 50 to 2000 km by latitude, season and time-of-day. These measurements are valuable to those whose primary interest is the ionosphere. They are of equal value to the physical chemist for use in theoretical analysis of the radiative and collision processes needed to produce the measured fluxes.

For the experimental aspect of this program, AFCRL during the two year reporting period instrumented some 20 rockets and satellites. The three instrumented satellites were the OGO-A, the Injun IV, and the SNAP-10A. OGO-A was launched in September 1964 with two AFCRL plasma probes for the measurement of the flux, energies, temperatures and densities of electrons and ions in the energy range 0 to 1 kev. Data from the flight was still being received, processed and analyzed at the end of the reporting period (July 1965). In November 1964, the Injun IV satellite was launched into a polar orbit. Two AFCRL plasma probes are also mounted on this spacecraft. The influx of low energy protons and electrons into the exosphere as well as the



AFCRL had several experiments aboard the Snap-10A, including the electrostatic probe (bar with dark ball on end) shown here in extended position.

spatial and temporal variation of ambient ion and electrons are being investigated. The SNAP-10A nuclear power generator, placed in orbit 3 April 1965, carried several experimental packages designed by AFCRL scientists to measure ion-electron densities, energy distributions of these charged particles, latitude and diurnal variations of charged particles.

Some results of rocket and satellite experiments are discussed in the following paragraphs.

On both day and night flights, sharp thin layers of ionization were observed in the vicinity of 100 km. These are presumably sporadic E. The relative importance of wind magnitude and direction on the occurrence of these phenomena is being investigated.

In the D-region in the vicinity of 65 km positive and negative ion layers are normally observed. No electron maximum is found at this altitude. Laboratory scientists have attributed this to the fact that the attachment frequency for collisions between electrons and O and O_2 to form negative ions is a major physical process in this region. The measured ratios of negative ions to electrons and positive ions to electrons have been applied in the continuity equation to deduce the cross section for associative and collisional detachment and radiative attachment to molecular oxygen.

The results of nighttime charge density measurement between 240 and 1875 km show that atomic oxygen is the principal ionic constituent below 530 km and ionized hydrogen the major constituent above 550 km. An upper limit is placed on the helium ion distribution which attains its maximum value at 550 km. At this level it constitutes a maximum of about seven percent of the total ion density.

A new value for the ion-atom interchange coefficient for the production of NO^+ has been obtained from the time variations of charge densities in the altitude region 280 to 300 km. The coefficient is found to vary between 2 and 4 x $10^{-12} cm^3 sec^{-1}$. The analysis also shows that diffusion of charged particles under the influence of the earth's magnetic field acts as a source of these particles below 300 km at night. The diffusion term changes sign slightly above this level.

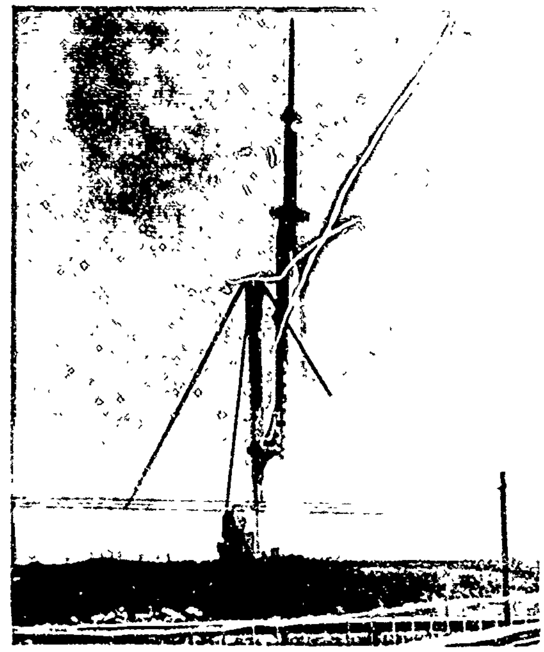
The diurnal variations of electron temperatures and ion and electron densities have been determined from satellite measurements in the F-region. Large diurnal variations of electron temperatures are observed between 200 and 330 km. The electron temperature is found to increase approximately

2000 degrees K within a few hours of sunrise and reaches a maximum shortly before sunrise. In the equatorial and auroral regions significant changes in temperature and charge density occur and are superimposed upon the diurnal variation.

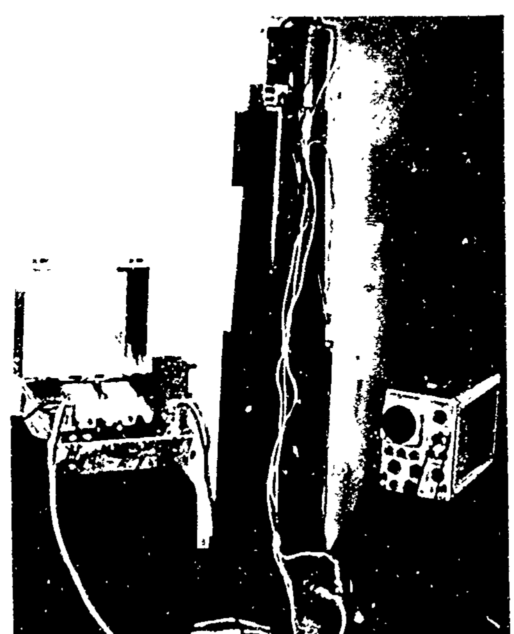
The goal of this work is not to measure the electrical structure of the atmosphere in ever finer detail. The ultimate goal is that of deriving a quantitative theory on energy mechanisms of the upper atmosphere. No such theory is presently in sight. Instead of deriving values theoretically, the scientist must still refer to measurements. Rocket experiments are costly, imprecise and time-consuming. But rocket measurements will provide the foundation for the formulation of theory.

AIRGLOW: Chemical reactions and collision processes following the absorption of solar ultraviolet energy result in the faint visible emissions of radiation known as airglow. The emissions occur at altitudes between 90 and 200 km. What kind of collisions and reaction processes between what kind of atmospheric species are needed to account for this chemiluminescence? The attempt to answer this question underlies AFCRL's airglow measurement program — and in this sense the airglow research program has much the same basis as the program for measuring the atmosphere's electrical structure. (Other airglow research at AFCRL is being conducted by AFCRL's Optical Physics Laboratory, Chapter VI, which is investigating emissions in the infrared region between one and ten microns.)

Night airglow and day airglow result from different energy transformation processes. But both are energy sinks, absorbing energy and releasing most of it in the form of airglow radiation



To measure the chemiluminescence mechanisms of airglow, rockets must carry instruments into the environment in which the chemical reactions take place. In lower photo, nose cone instrumentation for airglow and auroral observations is checked out before package is encased in rocket nose cone. Basic instrument is a scanning spectrometer.



rather than heat. The major emissions of both day and night airglow occur at 5577 and 6300 angstroms (oxygen) and 5893 angstroms (sodium).

The Laboratory program during the period was largely concerned with the collection of airglow measurements made since 1923 and reevaluating the data in terms of present knowledge of airglow mechanisms. From this study, it was established for the first time that solar flares trigger an enhancement of the 5577 emissions. A separate aspect of this study included a compilation of all measurements of airglow made in the equatorial regions, where only limited observations have been made. Diurnal, seasonal and latitude variations with respect to each of the three major spectral lines were analyzed.

A theoretical study of the luminosity profile of airglow emissions at 6300 angstroms for magnetically quiet conditions was carried out. The emission was assumed to arise from a two step mechanism involving charge exchange followed by dissociative recombination. Assumptions were also made with respect to the electron density profile. Using these assumptions the following parameters were calculated: the height of maximum luminosity relative to the electron density peak, the maximum luminosity, the layer thickness, and the behavior in the neighborhood of the maximum luminosity. The study included changes in the luminosity profile to be expected with changes in season and sunspot epoch.

Chemical reactions producing the aurora are sometimes undistinguishable from those producing airglow, although certain features of auroras — energy sources, their sudden onset — are not as well understood.

Why should the sunspot epoch enter into these calculations? The mechanism is only dimly defined. In a highly qualitative way, it is suggested that during active sun period an increased flux of free electrons and protons (originating in the solar wind) enters the earth's upper atmosphere — but indirectly, because the earth's magnetic field shields the upper atmosphere from direct entry. During active sun periods there is also an increase in variations in the geomagnetic index. Magnetic field variations affect the charged species (perhaps disrupting normal charge transfer processes) of the upper atmosphere and these influences add a new dimension of complexity to dynamic processes already exceedingly complex.

STUDIES OF THE AURORA: The aurora is still another manifestation of the chemical reaction, particle collision, and radiative attachment processes that form the common thread of this discussion of the physical chemistry of the upper atmosphere. But of the various upper atmosphere phenomena, the aurora is least understood. In some respects — strong emissions in the oxygen lines (5577 and 6300 angstroms) and the sodium line (5893 angstroms) — it has much in common with airglow. Still unexplained is the source of high energy particles needed to suddenly initiate and sustain the aurora.

AFCRL is conducting an ambitious program for gaining a better understanding of the aurora. During the two year period of this report, the Laboratory launched nine large rockets from the Ft. Churchill Range in Canada, a launch site within the aurora zone, to make direct and simultaneous measurements of upper atmospheric conditions associated with the aurora. Each of these rockets carried a number of individual probes. One rocket carried fourteen. Data were collected from such instruments as retarding potential probe, standing wave impedance probe, plasma frequency probe, plasma resonance probe, Langmuir probe, mass spectrometer, soft electron spectrometer, electrostatic analyzer, photometers, geiger counters, propagation experiment, scintillators, pulse and hot probes. In addition, simultaneous ground measurements were made with an ionosonde, all-sky camera, spectrometers, photometers, auroral radar, riometers and magnetometers.

The results of these flights have been, or will be, reported in the literature. Only one of the flights, one conducted from Ft. Churchill on 18 July 1964, will be discussed here — a unique flight to measure the daytime aurora.

The instrument flown was a one meter Ebert spectrophotometer with fixed slits set for a resolution of 11 angstroms and scanning the wavelength range 4000 to 5900 angstroms in seven seconds. The instrumental field of view was directed along the longitudinal axis of the rocket and viewed the sky through an opening exposed by the ejection of the nose cone tip. A 14-inch baffle and sunshade were mounted in front of the input slit to minimize the sunlight scattered into the instrument.

This same instrumentation was used in an experiment conducted by AFCRL six months earlier from the White Sands Missile Range in New Mexico to measure day airglow. Data from this earlier experiment proved to be very important in helping to define the upper border of the daytime aurora at Fort Churchill. In the earlier White Sands flight only one line — 5577 angstroms — was clearly identified as the day airglow line.

In the Fort Churchill flight two lines were unambiguously observed — 5577 angstroms and 4278 angstroms (N_2+). The highest altitude at which the 4278 angstrom line was recorded was taken to be the upper limits of the daytime aurora. This limit was between 113 and 123 km, an altitude typical of the upper limit of the nighttime aurora. The lower border of the daytime aurora was not determined.

The flight also gave additional data on day airglow. Above 123 km, the relative intensities of the 5577 angstrom day airglow line at both Fort Churchill and White Sands were comparable. The intensity of the line, however, fell off more rapidly with altitude at Churchill than at White Sands, indicating — possibly — a broader airglow layer in more southerly latitudes.

UPPER ATMOSPHERE CHEMICAL RELEASES: During the two year period of this report, AFCRL launched 26 sounding rockets carrying payloads of chemicals for release in the ionosphere. In addition, under Project Harp, a 16-inch Navy gun was used to transport 15 five-pound payloads of chemicals to altitudes as high as 160 km. Thus, the Laboratory's chemical release program

A 16-inch Navy gun was used to transport a 15 pound payload to altitudes as high as 160 km.

is one of some magnitude. The 26 rockets were the largest number used for any single AFCRL program.

The chemical release program, formerly carried the designation "Firefly," a project title changed during the period to "Redlamp." The scope of the program is extremely broad, having many aspects of potential operational application by the Air Force. But the program also offers a unique approach for observing atmospheric processes. One aspect of this program, discussed earlier, is that of using chemical trails as a tracer for measuring winds, temperatures, and densities.

Depending on the chemical used, it is possible to form an electron depleted region in the ionosphere, or a region of high electron density. From the standpoint of the physical chemistry of the atmosphere, it is possible to learn a great deal about chemical processes by observing what happens when natural atmospheric gases interact with chemicals of various types.

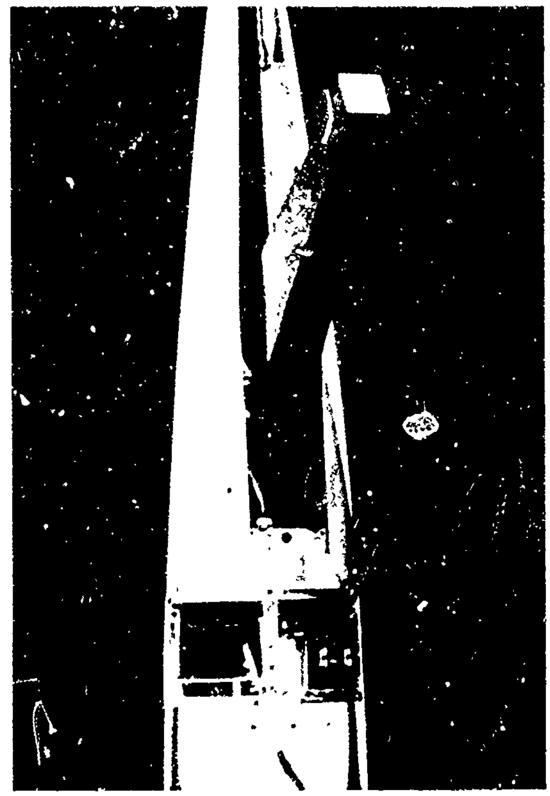
In certain chemical releases, the resulting glow is directly proportional to the concentration of atomic oxygen. Measurement of light flux enables, then, the determination of atmospheric oxygen, which plays such an important role in photochemical and chemi-ionization phenomena.

Upon release of aluminized compounds into the upper atmosphere, aluminum oxide (AlO) is obtained. When AlO is irradiated by sunlight, the molecular resonance bands are observed in the blue-green part of the spectrum. The relative intensities of the various bands are proportional to the temperature of the irradiated molecule. If this molecule is in equilibrium with the surrounding atmosphere, the ambient temperature can be determined by measuring the relative intensities of the AlO bands.

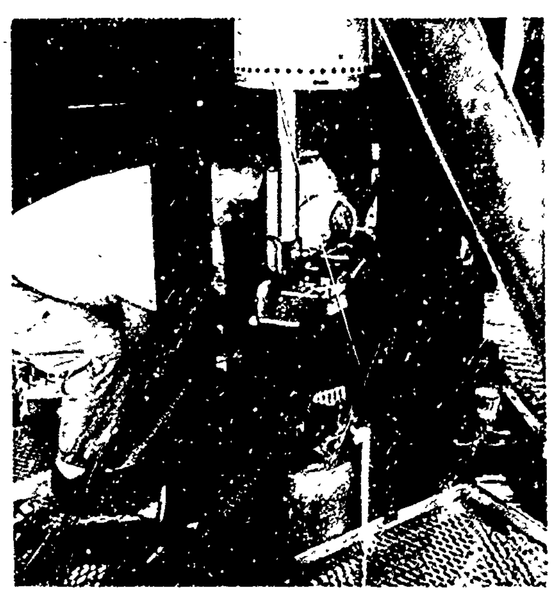
To interpret the radiative and ionization phenomena following the introduction of foreign materials into the upper atmosphere, Laboratory studies are concerned with reactions in gases at very low pressures. The mechanism of the reaction between oxygen atoms and various chemicals used in the release program — acetylene, nitric oxide, aluminum vapor, trimethyl aluminum and carbon disulfide — have been investigated, and in some cases quantum and ionization yields have been determined. Particular attention is being given to the reaction of nitric oxide with ground state and excited oxygen atoms.

AIR FORCE APPLICATIONS: By releasing chemicals into the ionosphere at an altitude of 90 to 120 km it is possible to create a dense electron cloud that persists for several minutes. This cloud can be used for over-the-horizon communications — and in fact TV pictures have been transmitted by reflecting the signal from such an artificially ionized cloud. During the reporting period, this application was explored further.

A second study made during the period concerned the detection of missile launches. Acetylene releases in the 90-140 km region resulted in glows with very similar spectral characteristics to those of the hydrocarbon burning missile plumes. The release of aluminized compounds is associated with a continuum radiation as observed in missile trails with aluminized propellants. Solid particles released at twilight scatter sunlight, the scattered light being highly polarized as are missile exhausts under twilight conditions. Carbon dioxide and sulfur hexafluoride, in view of their high attachment rates for free electrons, deplete the electron content in a portion of the ionosphere, resulting in holes in the ionosphere. Similar electron holes have been observed upon the passage of a missile through electron-rich regions of the ionosphere.



Since 1952, the biaxial pointing control, a servomechanism for locking the detector in the rocket nose cone on the sun during flight, has been part of all AFCRL rocketborne solar UV experiments. In lower photo, the pointing control is being installed in the rocket nose cone.



ULTRAVIOLET RADIATION

The energy required to initiate and sustain the dynamic process of the upper atmosphere is supplied almost entirely by ultraviolet and soft x-radiation (or XUV) from the sun. "Almost entirely" is inserted because a small, somewhat variable, and unmeasured fraction of the energy may come from the influx of particles associated with solar winds and solar flares. Ultraviolet energy is great enough to break molecular bonds and to start a rich variety of reactions (which infrared and visible light cannot do). One product of these reactions is the ionosphere.

AFCRL research on ultraviolet radiation has two parts. The first part involves rocket and satellite observations of solar ultraviolet absorption by atmospheric constituents at various altitude regimes and the direct observation of the sun's emissions of ultraviolet energy. The second part involves ultraviolet spectrographic studies within the Laboratory.

ROCKET OBSERVATIONS OF UV: During the reporting period, AFCRL launched six Aerobee rockets for direct measurements of solar ultraviolet radiation. Only by means of rockets and satellites can such observations be made since the atmosphere absorbs almost all ultraviolet radiation before it reaches the earth. Because each atom, ion and molecule (as well as the different energy states of each) absorbs ultraviolet radiation at different wavelengths, these direct observations provide an extremely valuable means of deriving information on atmospheric composition as a function of altitude.

The six rockets, all launched from the White Sands Missile Range, carried instruments to measure radiation in the wavelength range of from four angstroms (soft x-rays) to 1300 angstroms (ultraviolet) — although individually each rocket measured only segments of this span. The workhorse of these experiments was the biaxial pointing control, a servomechanism for pointing the detector in the rocket nose cone at the sun and keeping it there.

This servomechanism has been used regularly on such flights since 1952. The second standard workhorse was a grazing incidence monochromator. Still another standard instrument was a retarding potential electron detector.

The story of these rocket experiments is largely one of gathering increasingly refined data, and this is made possible through improvements both in the instrumentation (better diffraction gratings for better resolutions), and methods of telemetry. Of importance equalling that of improved instrumentation, is the application of knowledge gained from earlier flights to the design of subsequent flights. For example, nine spectral lines have been chosen as representative of relevant data. By restricting observation to these lines alone, resolution has been improved by a factor of 3.3.

Some of the general results:

1) For altitudes greater than 170 km, concentrations of atoms and molecules decrease exponentially with height.

2) Electron temperature values rise to values about twice that of neutral gas temperatures around 230 km.

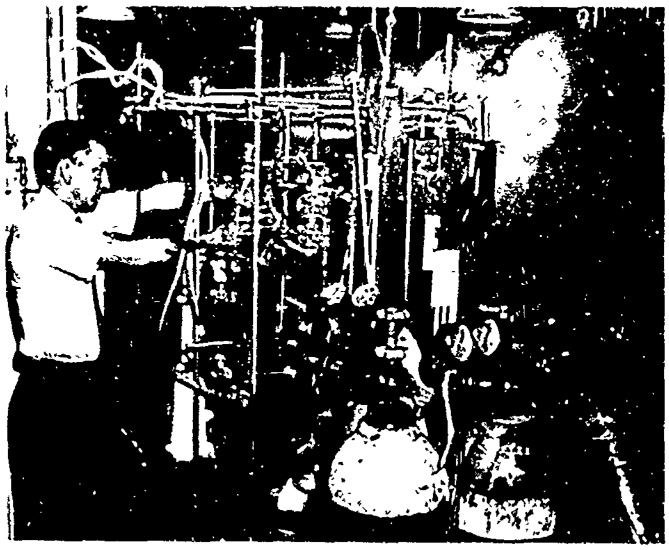
3) In comparing a flight made in December 1963 with flights made during the more active sun period of 1960 and 1961, no striking changes were noted in solar ultraviolet fluxes.

SATELLITE OBSERVATIONS: During the period, experiments were planned and UV observational instrumentation designed for incorporation on two NASA satellites scheduled for launch in the latter half of 1965.

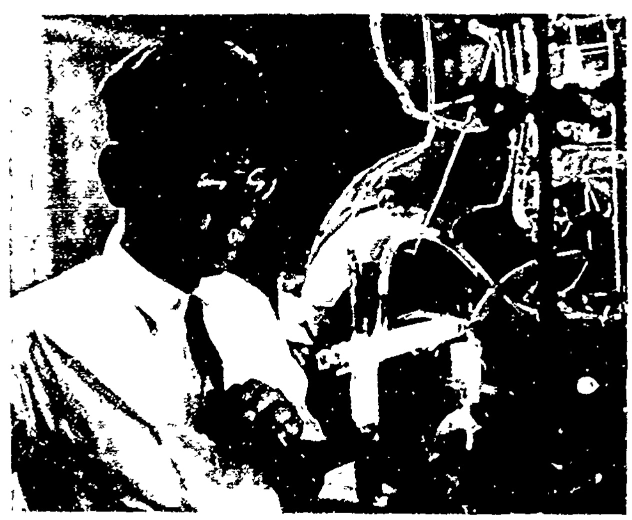
A photoelectric scanning spectrophotometer has been developed as a primary instrument for the NASA Orbiting Solar Observatory (OSO-C), scheduled for launch in August 1965.

This instrument, a grazing incidence grating monochromator, will be mounted on a solar oriented paddle of the spacecraft and will monitor solar fluxes in the 250 to 1300 angstrom range, integrating the radiation from the entire solar disc. Spectral resolution of the monochromator is about one to three angstroms. Upon ground command, scanning may be stopped at any one of 2040 steps or the scanning speed may be reduced. It is expected that interest in the resulting data will center on the long and short term variations in intensity of the strong line emissions from the abundant solar elements in various stages of ionization.

A more sophisticated spectrophotometer has been developed for the first of NASA's Polar Orbiting Geophysical Observatories (OGO-C). Using a stack of six diffraction gratings ruled in various ranges up to 90,000 lines per inch and two open-structure photomultipliers with three photocathodes each, the instrument will repeatedly scan the wavelength range of 170 to 1700 angstroms in six overlapping bands. This package, weighing only eight pounds, is the equivalent of six monochromators and will be mounted on one of the solar oriented paddles of the OGO spacecraft. The experiment will monitor the solar flux at wavelengths in the XUV range, and can be commanded from the ground to operate on selected short scans within this range.



Two of the Laboratory's large UV vacuum spectrographs are shown. In the upper photograph is shown the recently installed 6.6 meter spectrograph. Below in foreground is network of glass tubes for preparing gas elements for spectroscopic study, with another of the Laboratory's spectrographs shown in background.



MOLECULAR SPECTROSCOPY: Ultraviolet interaction with atmospheric atoms, ions and molecules can be studied under controlled conditions in the Laboratory. Only in the Laboratory can a particular atom or molecule be isolated for study. Here, large high-resolution spectrographic equipment can be used to resolve faint spectral lines. The essential purpose of these Laboratory studies is to discern the nature of the energy mechanisms which must exist to account for a given absorption or emission line of a given intensity.

For a number of years, AFCRL has operated some of the finest spectrographic equipment in the world for conducting such studies. This equipment consists of a one meter and a three meter normal incidence spectrograph, a one and a two meter monochromator, and a 6.8 meter grazing incidence spectrograph. During the summer of 1965, a new spectrograph, one having incomparable spectral resolution, was installed in the Laboratory. This is a 6.6 meter normal incidence vacuum spectrograph, operating in the region between 300 and 12,000 angstroms.

During the two-year reporting period, AFCRL spectroscopists have examined, explained or confirmed the energy mechanisms giving rise to scores of previously unobserved and unidentified band systems and spectral lines. A few have been selected for discussion:

1) Absorption bands of nitrogen, which occur in the 800-1000 angstrom region, have been studied previously, but vibrational quantum assignments for those bands had not been established. Work in this Laboratory with heavy nitrogen and a three meter normal incidence spectrograph has resulted in the establishment of such vibrational quantum assignments, principally through a study of the vibrational isotope shifts of those bands.

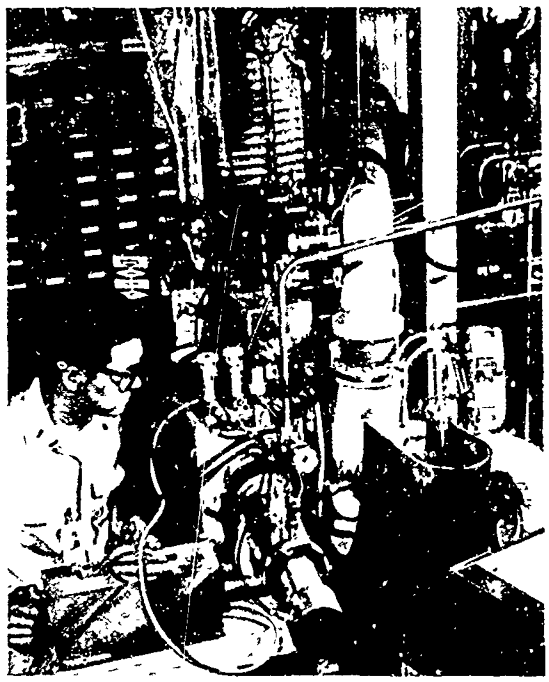
2) Five weak absorption band systems of nitrogen which occur in the 1080-1500 angstrom region were studied with a three meter normal incidence spectrograph. All five systems are forbidden systems according to selection rules. In this work previously existing ambiguities in identification of specific systems were removed.

3) Considerable effort was devoted to the study of afterglows of nitrogen. These studies were conducted in the 1080-1900 angstrom region for the purpose of finding the active substances which were responsible for the production of the afterglows. Previous results concerning the Lewis-Rayleigh afterglow were confirmed. That is, the active substances responsible for the production of this afterglow are nitrogen atoms in the ground state. For the Pink afterglow, it was found that vibrationally excited nitrogen molecules in the ground state were present in large concentrations in the afterglow.

4) The absorption spectrum of nitrogen while in an electrical discharge was studied in the 1080-1300 angstrom region. Strong absorption bands were observed in this region where ordinary nitrogen shows only very weak absorption bands. Those strong absorption bands were attributed to transitions from the vibrationally excited ground state to electronically excited singlet states which lie at or above about 12 ev.

5) A study was made of the emission from an electrical discharge in a mixture of a small amount of nitrogen with an excess of krypton or argon. The emission spectrum was found to consist of a few strong specific band systems in both cases. This type of selective excitation is due to transfer of specific amounts of energy from the rare gases to a few select upper states in the nitrogen.

CROSS SECTIONS: The concept of "cross section" was introduced earlier. The cross section is simply the reaction rate, or the probabilities of a reaction occurring among colliding particles. Cross section also refers to the probability that an atom or molecule will absorb a photon which will lead to an



Ionization and absorption cross sections of water vapor are being measured in the 600 to 1000 angstrom region using a one-meter, normal incidence-monochromator.

increase in the internal energy of the particle or the ionization of the particle. Thus for atmospheric gas molecules there are absorption cross sections and ionization cross sections. Knowledge of cross sections is therefore fundamental to the understanding of upper atmosphere processes.

The Laboratory is measuring cross sections for absorption and ionization of constituents of the upper atmosphere using improved techniques primarily developed in-house. Published during the period were measurements made by the Laboratory on absorption cross sections for N_2, O_2, CO, Ar, Kr and Xe between 580 and 1050 angstroms. Ionization cross section measurements are in progress. The Laboratory cross section measurement program, still relatively new, will be expanded during the next several years by further improving the techniques for obtaining higher resolution. A research effort to study the fluorescence of atmospheric gases as induced by UV radiation is also underway.

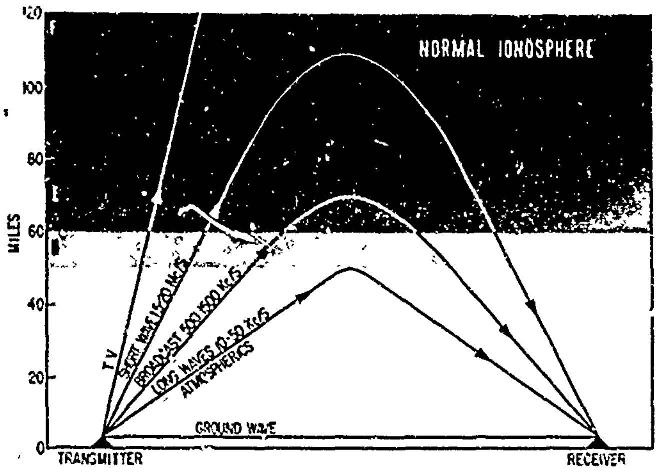
THE IONOSPHERE

Two previous sections, Physical Chemistry and Ultraviolet Radiation, dealt with the mechanism whereby the ionosphere is continuously created and dissipated by ionization and recombination. Gross features of the ionosphere are examined in this section.

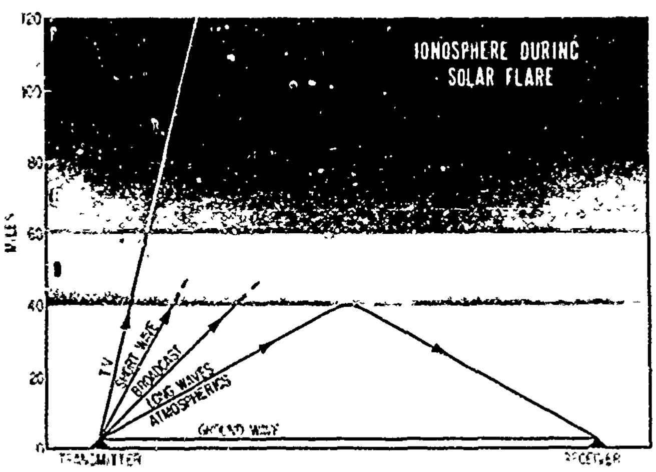
The ionosphere begins at an altitude as low as 30 km. It extends outward several thousand km. It is a tenuous, fragile mantle easily disturbed — by a rocket passing through it, by a nuclear explosion, by electromagnetic signals, by a solar flare, or by an acoustical soundwave of a jet. The ions and electrons that make up the ionosphere, even where most heavily concentrated (about 200 km), are only a small fraction of the neutral atmospheric constituents. The electron density at the highest point of concentration is only about 10^6 per cu cm — one-thousandth the neutral particle number at the same altitude.

For its studies of the ionosphere, the Laboratory operates several field sites and a thoroughly equipped aircraft (a KC-135) for making airborne observations. During the reporting period, this aircraft was flown all over the world — from the Arctic to the Antarctic on ionospheric research missions.

Radio techniques are the primary means for measuring the gross aspects of the ionosphere. The simplest of these radio systems are riometers — radio



The ionosphere is of Air Force interest because its changing character affects radio propagation. Radio techniques in turn can be used for evaluating characteristics of the ionosphere.



receivers that monitor the opacity of the ionosphere to radio energy from the sun, radio stars or from generalized galactic sources. The varying attenuation of these extraterrestrial sources is directly correlated with electron density at a particular time or location. The Laboratory has set up riometer monitoring stations all over the world.

Because radio techniques are so frequently used, there is often a broad overlapping between "ionospheric" research and "propagation" research, the latter being the subject of the final section in this chapter.

The Air Force has a direct interest in two aspects of ionospheric research. First, the ionosphere influences Air Force communication and detection systems. Second, the ionosphere may provide clues to the detection of missile launches, due to the fact that missiles passing through the ionosphere set in motion ionospheric waves that may be detected over great distances.

MISSILE-INDUCED IONOSPHERIC DISTURBANCES: A missile passing through the delicate and easily disturbed ionosphere can create ionospheric wave motions that radiate out over great distances. This wave motion is induced by the missile's exhaust. In the extremely low pressures of the upper atmosphere, the exhaust balloons outward several diameters larger than the missile itself. The streamlined missile penetrating the ionosphere does not produce the ionospheric wave; it is produced by the velocity of the outwardly expanding gas.

The disturbances are detected by radio reflection techniques. As the travelling ionospheric wave passes over an observer there is a change in electron density. The magnitude of the change is proportional to the intensity of the wave. The wave motion is detected by changes in phase of the reflected signal caused by the disturbance. Because the ionospheric height from which a radio wave reflects varies in a well-known way with the frequency transmitted, it is possible for the experimenter to select the altitudes at which the ionospheric disturbance is to be measured.

To study missile-induced ionospheric disturbances, AFCRL established several sites along the Atlantic Missile Range. By observing missiles launched from Cape Kennedy, the Laboratory hoped to learn more of the altitude, distance and time dependence of the ionospheric disturbances. Radio reflection and optical techniques were used to study missile exhaust characteristics as a function of the ionospheric shock waves they produced. The geographical configuration of the sites permitted measurement of the exhaust structure size as a function of angle of illumination.

From the observations of ionospheric disturbances, it is possible to characterize many features of the missile which created the wave — thrust and size, for example. Based on observations of Cape Kennedy launches, and the study of controlled ionospheric perturbations produced by AFCRL rockets, the Laboratory validated and refined a theory by which it is possible to derive missile parameters from the characteristics of the induced shock wave.

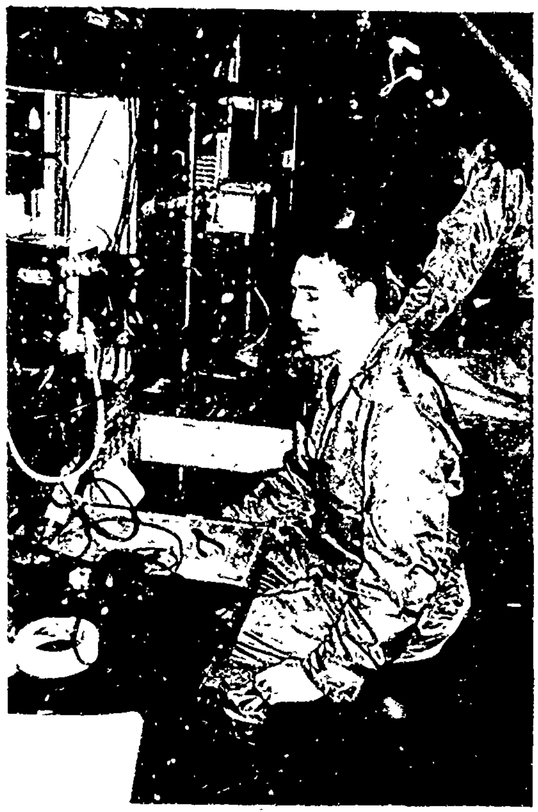
Another technique to measure the ionospheric wave motion consists of creating a chemiluminous trail followed by a high explosive release. The shock wave from the explosion can be visibly tracked as it travels along the trail and information about its velocity and intensity deduced. When this same type trail is generated in the vicinity of a missile launch the shock wave from the missile can be tracked through the trail.

In a related experiment, an Atlas missile and an AFCRL Nike-Apache rocket will be used in an experiment, scheduled for the latter half of 1965, to investigate the growth and intensity of missile-generated shock waves. The rocket, carrying a chemiluminescent chemical payload, will be launched at night from Little Carter Cay, 20 miles north of the Grand Bahama Island, in conjunction with the launch of an Atlas vehicle from Cape Kennedy.

The rocket will lay a chemical trail downrange from the Atlas' trajectory at an altitude range of 90 to 150 km. The Atlas missile will fly through the chemical cloud. Although the rocket will be fired within seconds after the Atlas is launched, the Nike Apache's downrange launch location and more rapid acceleration will allow it to disperse its chemical trail before the Atlas missile reaches the area within which the chemiluminescent trail is laid down. The resultant shock wave made visible in the chemical trail will be recorded by cameras situated in Florida at Jupiter, Vero Beach and Melbourne. Optical triangulation measurements will then be made from the photographic record.

ACOUSTIC WAVE COUPLING: A shock wave from a supersonic aircraft can be coupled to the ionosphere, and the resultant ionospheric disturbance can be detected by radio means. This was demonstrated in a series of experiments conducted by AFCRL using an F-104 as the primary source of energy. The trajectory of the aircraft was designed to focus the energy generated over a long flight path into a small region of the ionosphere being probed by a vertical incidence sounder. The aircraft was flown at a height of ten km, and acoustic focussing was intended for 110 km, approximately the E-layer maximum.

Analysis of the frequency spectrum of radio waves reflected from the ionosphere showed that in several tests perturbations occurred which were well correlated with the expected disturbance due to an acoustic wave propagating up through the E-layer.



Some of the interior instrumentation of the Laboratory's KC-135 is shown here. The aircraft is equipped to make a variety of measurements associated with the ionosphere.

This opens the possibility that a new tool may be available for ionospheric studies.

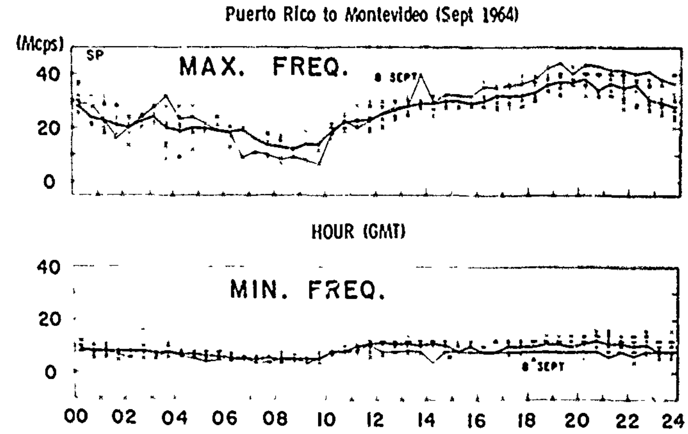
MAY 30 ECLIPSE EXPEDITION: The Laboratory conducted several experiments during the 30 May 1965 solar eclipse in the Pacific. One involved the Laboratory's KC-135 aircraft. Purpose of these flights was to observe the influences of the eclipse on the ionosphere. Several calibration flights were made before and after the eclipse. One, at 40,000 feet, was made during the eclipse itself.

The aircraft carried an ionospheric electron density recorder to vertically sweep a range of frequencies from two to 20 megacycles. The highest layer — the F_2 — was only slightly affected during the four minutes of total eclipse. This is particularly significant because it shows diffusion along the geomagnetic field lines. At the latitude of the observations, these field lines in the F_2 layer are horizontal. The amplitude of the ionospheric echoes from the F-layer recorded an increase of more than 40 db. This increase in amplitude, from signals that normally would be highly attenuated by the D-layer, indicates a considerable decrease of D-layer ionization during the four minutes of the eclipse.

An equally striking result — one not involving the ionosphere directly — was obtained in another experiment aboard the KC-135 to measure infrared emissions at 1.27 microns. During the eclipse IR emissions at 1.27 microns by O_2 decreased by a factor of four. This sharp decrease during the eclipse period will help in assessing some of the reactions between 50 and 80 km initiated by the photodissociation of ozone.

The Laboratory conducted a second 30 May eclipse experiment from Hervey Island in the Cook Island group. Here a radio receiver operating in the VLF range of six to 26 cycles was set up. The purpose of this test was to measure the amplitude of VLF solar emissions from the sun. Because of the wavelengths involved, this is difficult to do except in the special circumstances of an eclipse. Signal strength was recorded before, during and after the eclipse. From these data, direct solar VLF emissions can be calculated. Analysis of the results of this experiment had not been completed at the conclusion of the reporting period.

Two additional AFCRL experiments involving the 30 May eclipse were conducted by AFCRL's Space Physics Laboratory.



In these two recordings of reception made over an HF propagation path, it is seen that the lowest usable frequency (bottom) remains relatively stable while the maximum usable frequency varies greatly from hour to hour. Average monthly values are compared with variations during one 24-hour period.

SUNSPOT CYCLE AND IONOSPHERIC VARIATIONS: Ionospheric effects on HF propagation (3 to 30 Mcps/10 to 100 meters) are well-known — certainly by the ham radio operator. These effects vary with the solar sunspot cycle. During the reporting period, the Laboratory completed a study in which records of HF propagation in 1960, a year of moderate sunspot number, were compared with recordings made in 1963, a year of low sunspot number. Both studies used signals from station WWV in Maryland received at the Laboratory's Concord, Mass., site, 590 km from the transmitter.

High frequency propagation is particularly sensitive to electron density variations. As electron density increases, the HF band opens up with more useable frequencies toward the higher end. But at the same time there is a slight contraction of the useable frequencies at the low end of the band. On balance, however, the spread of useful frequencies is greatest with high electron densities. This means that, contrary to common belief, propagation characteristics are improved during active solar periods, except during periods of magnetic disturbances which are more frequent during active solar periods. The effect of these disturbances is to deplete electron concentrations.

The study shows that during the moderately active sunspot year of 1960, average magnetic disturbances had a quicker and longer lasting effect on the MUF (Maximum Useable Frequency) than did disturbances during the quieter year of 1963. In 1960, magnetic disturbances brought about the greatest reduction in the MUF on the day the magnetic disturbance occurred. In 1963, the greatest reduction of the MUF occurred a day later. But in 1963, the MUF effect was of shorter duration. Curiously, there was no parallel pattern for the LUF (Lowest Useable Frequency). The onset, intensity and duration of the LUF changes were the same for both years studied.

Another finding is that during the period of low sunspot number, the normal seasonal variations of the MUF (hence, seasonal variations of electron densities of the F_2 layer) are not as great as the variations during the period of moderate sunspot number.

SATELLITE PROBES OF THE F_2 LAYER: Probes in satellites permit the scientist to sweep broadly through the earth's F_2 region. AFCRL instruments (standing wave impedance probes) for measuring the densities of the charged particles making up the F_2 layer were carried aboard several satellites during the reporting period. While ground-based HF investigations of the type discussed above can provide general information on F_2 electron densities at a single point between transmitter and receiver, satellites provide a means for obtaining fine grain features over much of the earth.

With satellites, the Laboratory observed several ionospheric irregularities. Many previous observations had established the general contours of the F_2 layer. It is not an evenly-featured mantle about the earth. The concentrations of electrons and ions vary widely with altitude and latitude in a fairly well-defined pattern. In the F_2 region and below, maximum and minimum densities of the layer at any given altitude occur at the same general latitudes. At the magnetic equator, minimum densities are found with maximum densities occurring at about 20 degrees latitude. This pattern changes, however, at altitudes well above the F_2 layer. Here maximum densities occur at the magnetic equator, and decrease toward the poles. Although there is an increased electron density at high altitudes in the auroral regions, these densities may result from electrons in the outer radiation belt rather than in the ionosphere.

As a result of AFCRL satellite instrumentation, it was discovered that superimposed on this general pattern are marked irregularities in the south polar region (above the F_2 maximum), and near the earth's magnetic equator (at the F_2 maximum). Within relatively short distances in these regions, the electron density fluctuates widely. These irregularities can be thought of as mottled, somewhat random patches of electrons. Also it was found that around the maximum of the F_2 layer, at all latitudes, irregularities occur with density variations between five and ten percent, over areas as small as a few hundred km.

SPORADIC E FORMATION: Sporadic E is a concentration of ions in the E region. Just how these ion clouds are formed has been something of a mystery. One hypothesis attributes the formation to wind shear action. During the period, the Laboratory carried out a number of experiments to verify this hypothesis.

The experiments, conducted at Eglin AFB, Florida, involved the release of luminous chemical trails by rockets which provided a tracer to observe wind shears and an ionosonde to detect the presence of sporadic E. Wind shear is defined as a sharp change in wind direction with altitude. Sporadic E is associated with east-west wind shears. The explanation, in general, is based on the action of a moving charged particle in a magnetic field. Since any charged particle moving through a magnetic field is acted on by a force which is perpendicular to both its direction of motion and the magnetic lines of force (except when the direction of motion parallels the lines of force), the charged particles carried along by ionospheric winds are pushed vertically (up or down) by the earth's magnetic field. The force it exerts on them is at maximum if they are travelling in an east-west direction. In the case of positive ions, those travelling with a west wind will be pushed downward while those travelling with an east wind will be pushed upward. Thus if there is a west wind directly above an east wind — a maximum negative east-west wind shear — positive ions will tend to collect between the two winds, forming a localized layer of high ion density. Because sporadic E occurs near maximum negative east-west wind shears, it is believed that the above process may account for its occurrence.

MAGNETIC FIELDS AND THE IONOSPHERE: A classic physical principle is that charged particles — electrons and ions — interact with magnetic fields. This is the basis for the theory discussed above with respect to the formation of sporadic E. Another manifestation of magnetic field charged particle interactions is the electrojet. An electrojet is a strong electrical current in the ionosphere's E region. Such currents are found near the earth's magnetic equator and are believed to be coupled somehow to the earth's magnetic equator. In January 1965, the Upper Atmosphere Physics Laboratory and the Space Physics Laboratory (Chapter IV) launched six Nike Cajun and Nike Apache rockets from an aircraft carrier off the coast of Peru into the equatorial electrojet. In addition, the Laboratory's KC-135 ionospheric aircraft was used on two major expeditions during the period to measure properties of the electrojet.

Ionospheric influence on radio propagation is graphically presented in conventional pen recordings which are analyzed to determine ionospheric charges.

Still another study relating to magnetic fields and charged particles, a highly theoretical one, concerns the ionosphere only tangentially. The study involves well-known concepts of hydromagnetics in which changes in any one of three basic parameters — magnetic field, electric field, and velocity of a conducting medium — induce changes in each of the others. In this study the motion of the charged particles in the outer atmosphere (in the upper ionosphere and the radiation belts) under the combined action of the earth's rotation and the solar plasma wind is considered.

The earth's ionized atmosphere extends out several earth radii. This region is compressed by the solar plasma wind on the side of the earth facing the sun. On the night side of the earth, the magnetosphere expands outward. Because the atmosphere in this region rotates with the earth, the outer atmosphere alternately contracts and expands as it moves toward and away from the solar plasma wind. Thus there exists a moving conducting medium (the atmospheric plasma) in the presence of a magnetic field, and this results in an electric field. The electric field oscillates with a period of one cycle per day.

This electric field, originating in the outer atmosphere, reaches down to the ground. Because the surface layer of the earth is conductive, a current is induced. The current system is, of course, very weak. It varies with latitude. But it is well capable of yielding measurable diurnal magnetic field variations on the ground.

The earth surface current concept illuminates several geophysical phenomena. If the earth current system gives rise to a magnetic field, then it should be expected that this magnetic field would vary with the conducting properties of the earth's surface layer. Because oceans have a higher conductivity than land masses, one would expect some slight differences in the variable magnetic field at different locations on the earth. Certain observed peculiarities of the magnetic field may in fact indicate such geographical influences.

Another implication of the study concerns effects in the ionosphere. The electric field in the ionosphere depends also on the currents produced in the earth's surface layer. The geographical structure of the earth should consequently have some influence on this electric field and on motions of the ionospheric plasma. This may contribute to observed differences in ionospheric characteristics in different parts of the world.

RADIO PROPAGATION

This section is concerned with transmissions of radio energy and with factors that attenuate or modify this energy during transit between source and receiver. This research is focused on the transmission of radio energy, as such — not with radio energy as an analytical tool for ionospheric investigations.

The primary attenuating and modifying influence on radio energy is the ionosphere. The aurora and the earth's magnetic field also affect radio propagation. The research covered in this section is of potential interest to the designer of communications, detection and antenna systems.

SATELLITE TO SATELLITE PROPAGATION: Radio transmissions from one satellite to another will be attempted for the first time by AFCRL scientists in August 1965. The key feature of this experiment is not simple line-of-sight transmission, but the transmission between satellites on opposite sides of the world. Primary purpose of the experiments is to measure attenuation, signal degradation and reliability of radio propagation between space vehicles as a function of distance between transmitting and receiving satellites.

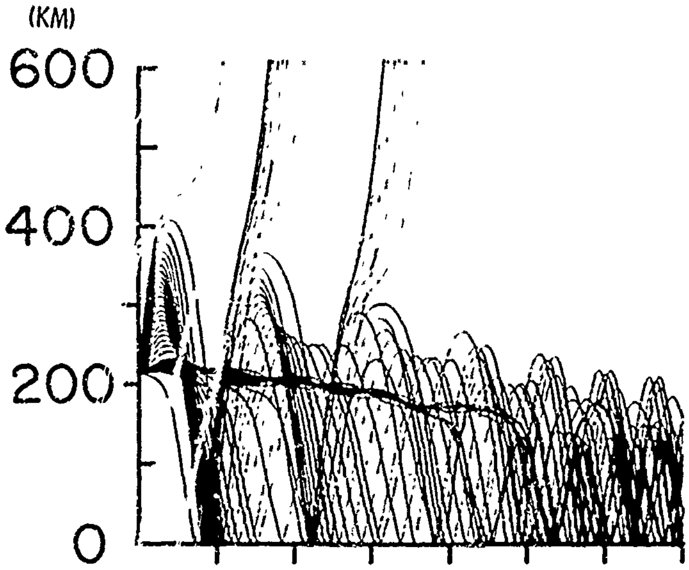
The experiment entails the launch of a single satellite. A radio transmitting package will be ejected from the satellite after launch and placed into the same orbital plane as the mother satellite. The mother satellite will receive signals from the smaller satellite and transmit data to ground receivers. The ejected package will be given an initial separation velocity so that in five days it will be separated about 20,000 km from the mother satellite — a distance that will place it on the opposite side of the world.

Transmissions will be made at 6.8 and 13.6 Mcps. A pulse modulated signal with pulse durations of 250 to 750 microseconds will be transmitted on each frequency. The satellite will be placed in a roughly circular orbit at about 200 km altitude. During the five to ten day lifetime of the transmitting satellite, the signal intensity and degradation in the shape of the received radio pulses will be measured. The degree of pulse shape degradation indicates the rate and reliability that can be achieved in information transmissions

Transmissions between satellites located on opposite sides of the world is possible because the radio energy is trapped in the ionosphere. Trapped in the ionospheric duct or channel, the signal may travel over great distances with relatively low attenuation.

In a somewhat related satellite experiment, one conducted in conjunction with the Space Physics Laboratory (see Chapter IV), two beacons, each with a one-watt cw output and operating at five and ten Mcps were placed aboard a satellite to investigate the ionospheric ducting mechanism. Rather vivid results were obtained. Signals were trapped, ducted over great distances, and actually detected by ground antennas on the opposite side of the world when, due to some ionospheric inhomogeneity, the signal escaped the duct.

The behavior of radio signals of a given frequency transmitted at a given altitude was entirely predictable largely as the result of an AFCRL study under way for several years on ray tracing, discussed below.



A 10 Mcps signal from a satellite at about 200 km takes many paths, as shown on this chart. Over the 1000 km representated, it is seen that many rays pass into space, but most are reflected between earth and the ionosphere. Those rays traveling along a horizontal path are rays trapped in an ionospheric duct. The computer shown below is used by AFCRL to calculate these ray paths.

RAY TRACING STUDY: What kind of path will a radio signal of a given frequency take during transit between transmitter and receiver? This depends on many things — latitude, direction of propagation, season, altitude of transmitter, and time of day. Varying electron density is the primary determinant of the path taken by a radio signal. There is, of course, never a single path taken by a signal between transmitter and receiver, but a near infinite number, most of which are slight departures from a mean.

The ionospheric and magnetospheric index of refraction varies with three space coordinates and, due to the presence of the geomagnetic field, also with the direction of propagation. Because the refractive index distribution is inhomogeneous, the ray paths followed by radio signal energy emanating from a transmitter are complicated and often form unusual ray patterns. These patterns can be obtained by solving a set of simultaneous differential equations. AFCRL operates a large analog computer solely for its research in ray tracing.

The need for differential equations arises from the fact that the maximum electron density varies by a ratio of seven to one in going from noon to midnight longitude along the direction of propagation. The height of the F-layer peak varies within a 150 km interval between noon and midnight.

Ray tracing research conducted by the Laboratory involves 1) observation, 2) calculations and machine computations leading to ray path prediction, and 3) observations again to verify predictions.

Observation entails the operation of several propagation paths. During the reporting period oblique-incidence propagation paths were operated between Uruguay and Puerto Rico, and Puerto Rico and Bedford, Mass. These paths were used to test transmission and reception of signals at 160 discrete frequencies within the band from four to 64 Mcps. By plotting maximum and minimum detectable frequencies and the bandwidth of total received frequencies, information on the path taken by a signal of a given frequency between transmitter and receiver can be derived.

Another propagation path that yielded valuable data was one between WWV in Maryland and AFCRL's Concord, Mass., site. This path was used to measure amplitude and phase of two closely spaced frequencies. This is done by using two narrow filters at the receiver, spaced 600 cycles apart. Reception was at 5 and 5.0006 Mcps. In spite of this narrow separation, differences were found in recorded signal strengths. In particular, polarization fading (Faraday effect) differences were found that may be useful for several purposes, such as the estimation of the total electron content along the radio transmission path.

MAGNETOSPHERE PROPAGATION: Compared to the complexity of ray tracing (above), the propagation of a signal along a geomagnetic field line is a relatively simple concept. This mode of propagation was investigated early in 1964 during a two-week flight to the Southern Hemisphere by the AFCRL KC-135. HF transmissions were made from Scituate, Mass., and Hanover, N. H. The KC-135 aircraft, operating out of Buenos Aires, was flown to Antarctica at the area magnetically conjugate to the point of transmission from the Northern Hemisphere.

The propagation of HF radio waves along field-aligned ionization gradients (geomagnetic shells $L=3.5$ and $L=1.6$) was investigated. Both pulse travel time and Doppler shift techniques were employed to detect these magnetospheric signals and to differentiate them from signals propagated via the ionosphere. Using Doppler shift techniques, a signal component was detected with the frequency shift predicted for magnetospheric propagation. This signal had a path loss of 135 db which was about 30 db greater than the loss for the ionospheric path. A great deal more experimentation is required in order to build up significant statistical evidence for or against magnetospheric propagation.

VLF STUDIES AND SFERICS: Very low frequencies (3 to 30 kc) are used for long-range communications and radio direction finding — Loran being an example of the latter. VLF radio energy can travel great distances in the cavity between the earth and the ionosphere. Investigations of VLF propagation carry the researcher into the broader area of sferics — lightning discharges. Lightning discharges generate a sharp VLF pulse that can be detected thousands of miles away. Closely resembling the waveform of the sferics pulse is the waveform of a VLF pulse generated by an atomic explosion. Much research is underway on techniques to clearly distinguish between a VLF pulse from sferics and a similar pulse from a nuclear detonation.

The Laboratory operates two sferics monitoring networks in New England which can detect and locate the point of origin of large sferics occurring over most of the world. The largest of these is centered at Mt. Wachusett in Massachusetts. Three receiving stations (defining a triangle with 90 mile sides) are linked by microwave data links to Mt. Wachusett. A second network consists of three stations arranged in a triangle with 66 mile sides. One corner of the triangle is L. G. Hanscom Field, Bedford, Mass.

The VLF research has two main goals: 1) the accurate location of sferics occurring hundreds of miles away, and 2) changes in the sferics waveform during transit over great distances. The pulse, as recorded at the receiver, can differ significantly in shape from the shape at the time of generation. Among the influencing factors are: 1) variations in the earth's conductivity, 2) diurnal variations in the effective height of the ionosphere, 3) direction of propagation with respect to the earth's magnetic field, and 4) unpredictable changes in the ionosphere caused by solar flares, proton events, auroras, and so on.

VLF ROCKET EXPERIMENTS: In connection with the above work, two Exos rockets were flown on 25 May 1965 in an experiment designed to investigate the VLF frequency propagation and absorption characteristics of the D and E regions of the ionosphere between 40 and 200 km. Instrumentation consisted of a loop antenna carried in the fiberglass nose cone of the rockets, and a four-frequency receiver. VLF transmissions were made from four widely spaced locations — Maine (17.8 kc), Maryland (21.4) kc), Washington (18.6 kc), and Hawaii (26.1 kc). These signals were received at a ground station at the launch site, and by the receiver in the rocket. The signals received at the launch site and in the rocket were compared to determine phase shifts, delays, and amplitude differences. Ground-based receivers were identical to those in the Exos rockets.

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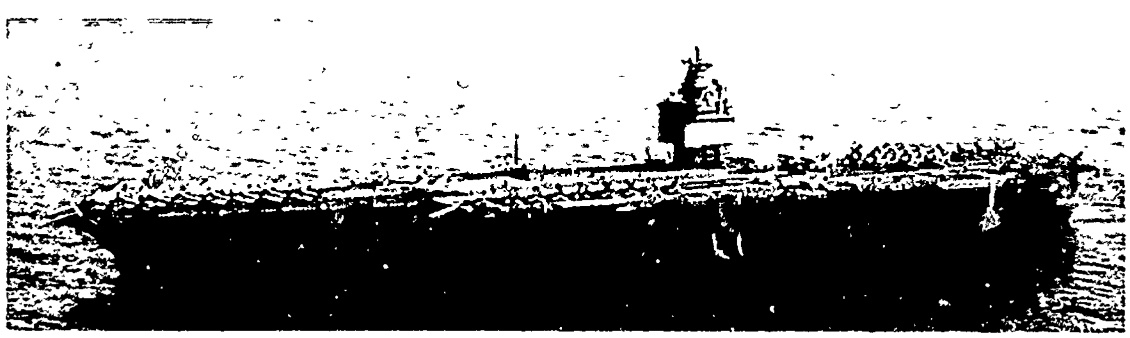


Products of research are often unpredictable and the pathway from feasibility to application is seldom direct. Three novel antennas of the atomic carrier Enterprise had their origin in the late 1940's and early 1950's at AFCRL — a fact generally lost to history. Two of the antennas dictated the distinctive configuration of the island of the carrier, the flat sides and the unique dome structure. A smaller antenna, not visible in the photograph, is one used to establish the glide paths for landing aircraft.

III Microwave Physics Laboratory

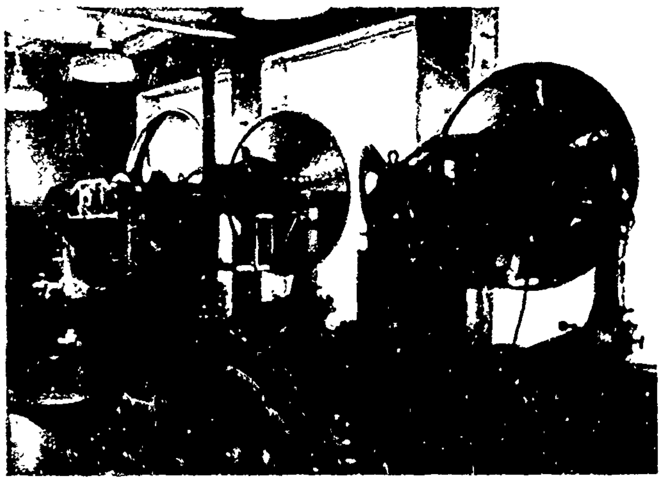
The program of the Microwave Physics Laboratory is centered on antenna theory and design. From this center, however, the program extends into the broader field of electromagnetics to include propagation, communications, coherence and scattering theory, interaction of electromagnetic energy with plasmas, and the generation of microwave phonons.

From research in antenna theory has come a multiplicity of new insights into the behavior of electromagnetic energy in space and the relationship of spatial influences to optimum configurations of antenna elements. These studies have provided the systems designer and engineer with new tools for the analysis and evaluation of antenna performance. These new theoretical insights are related to certain concepts of communications theory and optical physics. Although this approach is in itself not new, it has been only within the past year or so that its potential has been realized in connection with problems of antenna design.

A number of antenna design concepts were developed or reached fruition in the form of experimental models during the period. One of these is the short backfire antenna, which promises unique advantages in size, economy and performance over conventional antennas of the Yagi type.

The Laboratory's program in plasma physics represents a fine balancing of theoretical and experimental research. Although the core of the program is devoted to techniques for transmitting radio energy through the ionized envelope surrounding a nose cone or space vehicle during reentry, the overall plasma physics effort is much broader in scope. The research illuminates all interaction mechanisms of radio energy with plasmas of varying densities and compositions.

The generation of microwave phonons—essentially acoustical crystal lattice vibrations—at higher and higher frequencies has two potential applications. First, by appropriate transducing mechanisms, it is possible to derive electromagnetic oscillations in the extreme millimeter wave region. Practical and efficient delay lines have already resulted from the research making possible delay time of many milliseconds with a device several centimeters long compared to the hundreds of feet of waveguide needed for storing microwaves or microwave pulses. Next, the study of acoustic vibrations in crystals gives the crystallographer another analytical technique for evaluating the properties of the crystal.



At the Laboratory's antenna range at Ipswich, Mass., are many antenna test facilities, among them being these three transmitting antennas operating at K, S, and X bands used to evaluate patterns of receiving antennas located at varying distances away.

In propagation and communication, Laboratory efforts are rather narrowly focused on two extreme regions of the spectrum. In the very low frequency region, the Laboratory is investigating methods for propagating a signal through the earth's crust, the goal being hardened communications over relatively short distances. In the millimeter wave region, the Laboratory, by means of a new high precision 29-foot parabola placed in operation in 1964, is studying atmospheric effects on signals in the 35 gc region. The millimeter wave communications program is the newest of the Laboratory programs.

The research reported in this chapter is related to the basic Air Force operational needs of improved communications, detection and reconnaissance capabilities. Since the last reporting period the center of gravity of this Laboratory has shifted slightly toward the basic research end of the R&D spectrum—with more emphasis on theory and a corresponding decreased emphasis on the design of experimental antennas.

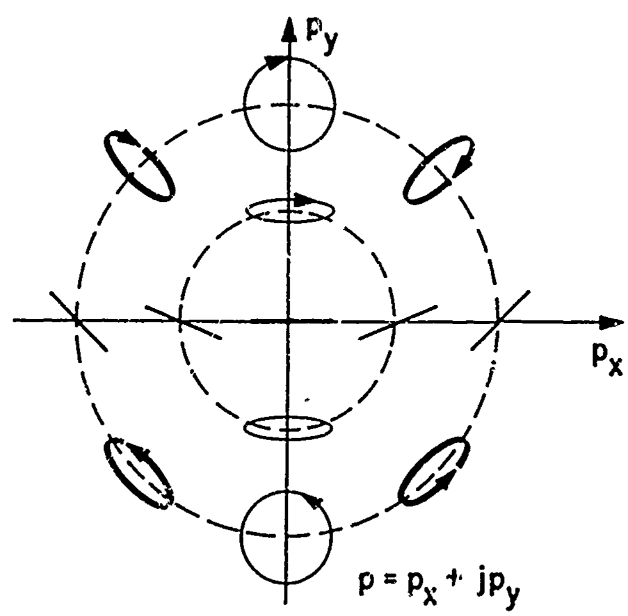
ANTENNA THEORY

The products of antenna theory are criteria to be used by the antenna designer for optimizing antenna systems. Antennas are data gatherers for many Air Force systems and to a great extent define the limits of systems capability. While antenna technology has been evolving toward more precise control of aperture distributions, antenna performance is still being specified largely by gain, beamwidth, and sidelobe levels. These criteria are insufficient for the antenna designer. He cannot predict quantitatively the performance of new antenna designs without precise theories relating the antenna parameters and the EM information being gathered.

Antenna theory encompasses electromagnetic theory, the theory of partially coherent waves, communications theory, and aspects of diffraction and scattering. In much of the theoretical work of the Laboratory there is a strong common thread. There is the special emphasis placed on coherence properties of the propagated wave. Several years ago, AFCRL published several papers on coherence which have since become standard references in coherence analysis. It was shown that in any mathematical analysis of a propagating wavefront, the wave can never be considered as either fully coherent or fully incoherent. Such propagation must always be thought of as partially coherent. The earlier formulations on partial coherence were re-examined and strengthened during the period.

ELECTROMAGNETIC THEORY: Several important papers dealing with electromagnetic theory were published during the period. Together, these papers serve to remove some of the principal paradoxes found in Maxwell's classical theory.

Work in basic electromagnetic field theory has centered on the concept of covariance. While it is true that the mathematical theory dealing with the transformation properties of differential forms—"covariance" theory—is a rather complicated mathematical discipline, its application to physics can lead to important physical consequences, if appropriate methods are used. The problem is that of correlating in a physically unambiguous manner physical observations with respect to different frames of reference. From the point of view of physical theory, the most significant aspect of this work was the demonstration that the correct covariant form for the field equations is unique, and not to a certain extent arbitrary, as had been thought. In this covariant formulation, electromagnetic fields in moving (especially rotating) media can now be treated correctly, and the electromagnetic equivalent of inertial mass has acquired new theoretical potentialities. When it was discovered several decades ago that mechanical inertia is associated with electromagnetic energy this led to the tempting notion that, perhaps, all mass could be of electromagnetic origin. Others later showed that mass cannot be of a purely electromagnetic origin,



Partially polarized electromagnetic radiation can be obtained by simple geometric considerations. Here are seen some of the geometrical relationships between linearly polarized and elliptically polarized waves with respect to points on a plane. Such studies are some of many aspects of EM theory.

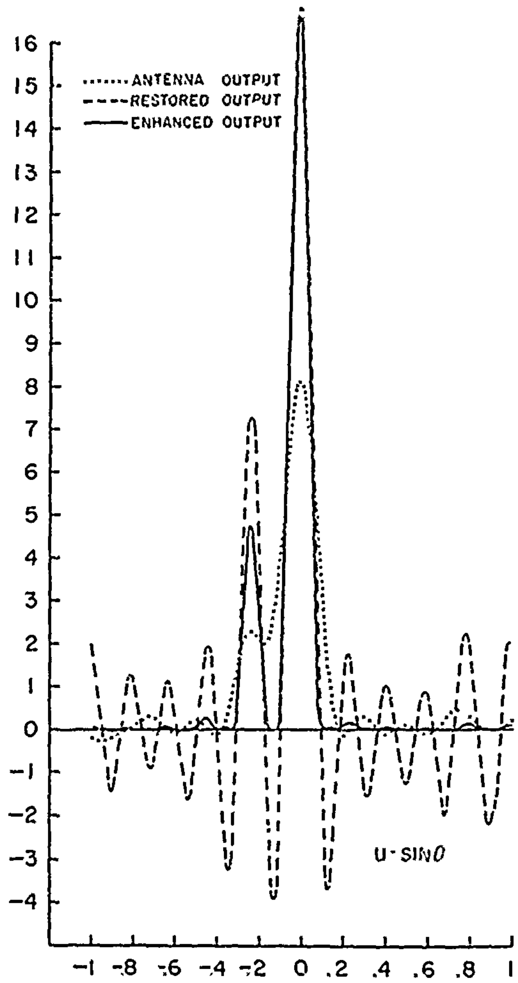
but their reasoning was based on a covariance deficiency and was not wholly satisfactory.

In a paper published in the 3 February 1964, *Physical Review* titled "Radiation Forces in Inhomogeneous Media," an AFCRL scientist extends the operational potential of the commonly used expressions for energy and momentum conservation. By modifying certain assumptions and by accounting for interactions, he evolved a more coordinated description of energy-momentum relationships.

Other work in electromagnetic theory is centered on electromagnetic potentials, on vortex formation in plasmas, and on variants of the Sagnac experiment (rotating electromagnetic fields).

Re-examined during the period were the formalisms dealing with "partially coherent" fields. This re-examination has brought a significant result. It was shown that the basic equations for second- and fourth-order coherence effects cannot be based on an adaption of Maxwell's equations to random functions, as had previously been thought, but must be based directly on the wave equation for the field probability amplitude, previously known (but not used in this connection) as the second quantization of electromagnetic fields. The practical implication of this result for all problems dealing with ordinary coherence effects (including light fluctuations, as in intensity interferometry) is that these can be solved within a much simpler formalism than that currently used in coherence theory.

In a completely novel approach to the analysis of partially polarized electromagnetic waves, the Laboratory, in another study, looked at electromagnetic waves from the standpoint of geometric models. The partially polarized plane wave is treated in two four-dimensional spaces. From the four-dimensional space, a three-dimensional space is derived. Several models were constructed. From the study of these models, invariant properties and certain relationships of partially polarized waves are shown with a lucidity never before obtained.



Resolution of surveillance and reconnaissance antennas used to scan ground targets (incoherent sources) can be greatly enhanced by processing the frequency components of the source spectrum. The process involves smoothing radar data and restoring it to obtain the improved resolution depicted here.

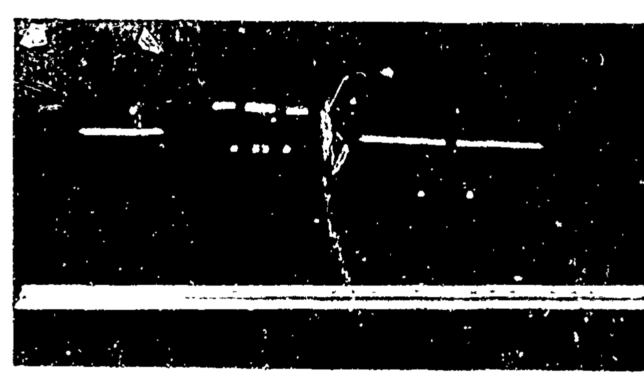
ANALYSIS OF SCATTERING: Scattering (or more loosely, reflection) of radio energy from an object is, obviously, fundamental to radar. Mathematical formulations on scattering from realistic objects (as against idealized shapes) is inordinately complex. Scattering considerations are directly germane to radar detection, reconnaissance and mapping, radar camouflage, and to techniques for reducing the radar cross section of Air Force missiles or satellites.

A special scattering problem—one of great interest to the Air Force—is that of reducing or suppressing the radar return from an object—and occasionally enhancing the scattered signal. What is involved here, essentially, is finding techniques for controlling the scattering properties of a body. As a first step, a better understanding of the interaction of electromagnetic radiation with a material object is required.

One approach is through reactive loading. By reactive loading is meant the placement of a reactive impedance of some sort on the surface of the object from which energy is to be reflected. The loading must be related to the wavelength being transmitted.

Results have been obtained for an idealized surface loading structure. The structure consists of a cavity just beneath a plane conducting surface. There is an aperture or slot coupled to a cavity, through which the energy may enter and exit. If the size of the cavity and opening are properly designed, it is possible to achieve a marked reduction in reflected energy. An enhanced return is possible if the cavity parameters are altered so that the energy from the cavity is emitted in phase with the signal reflected from the surface of the object.

Experimental studies were made to determine optimum direction of inci-



Radar signals reflected from targets can be greatly enhanced or reduced by reactive loading techniques, or by the configuration of the target reflector. Shown here are some of the shapes constructed and evaluated for their reflecting properties during the reporting period.

dence and polarizations for exciting the cavity. Further studies were made to determine how cavity dimensions may be adjusted to control the amplitude and phase of the reradiated energy. While the Laboratory's highly rewarding results were specialized to thick dipole or rod-like objects, the results are qualitatively valid for a variety of practical structures. Recently an AFCRL contractor has shown that the same principle can be applied to significantly reduce the scattering from a spherical body with a reactive load slot on the surface.

In a joint contractor/in-house effort the analysis of a new exact solution to the problem of determining the electromagnetic scattering from a highly conducting finite cone was completed. The results of the analysis have yielded theoretical values of the radar back scattering cross section for an excitation along the cone axis. The theoretical results exhibit anomalous resonances which, it is hypothesized, are due to resonances in the cone edge currents. The validity of the new results are presently being checked experimentally at the AFCRL Ipswich test site.

ANTENNA ARRAYS: A basic antenna configuration is the array which consists of a number of identical radiating elements. Such arrays provide the theorist with a number of variables to play with—signal phase and amplitude at the radiating elements, element spacing, and number of elements. There is presumably an optimum array configuration of each particular application, with optimum expressed in terms of relationships between desired beamwidth, low sidelobes, directivity and so on.

In the field of antenna arrays of uniformly spaced elements the Dolph-Chebyshev design is classic. It represents an array whose radiation pattern possesses optimum beamwidth or sidelobe properties. Numerous attempts have been made to simplify the process of calculating the required element excitation coefficients for this array. In all cases the formulas generated have proved unduly complicated, and particularly so for element spacings that are less than half-wavelength.

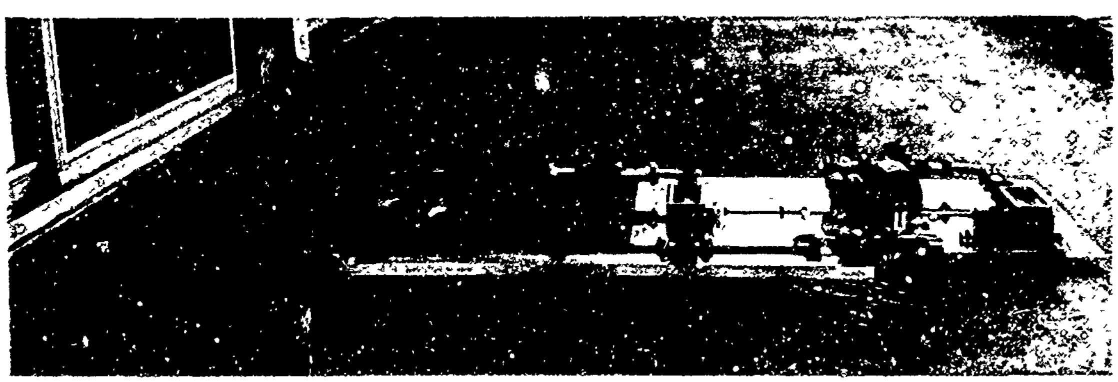
Laboratory research has led to the development of two alternative means for the exact evaluation of these coefficients that hold for arbitrary element spacings greater than or less than half-wavelengths. These techniques remain quite useful for arrays that are not of excessive size, say, less than 20 elements. Further research has, however, led to the development of a very accurate approximate solution for these coefficients. This is valid for arrays with numbers of elements in excess of 20. Moreover, it provides an extremely useful means for discovering the effect of variations in element spacing on the general nature of the array aperture distribution. Extremely simple expressions for both directivity and beamwidth have been obtained for Dolph-Chebyshev radiation patterns subject to electronic scan. By means of these simpler expressions for beamwidth and directivity, information has been obtained relative to the specific sidelobe level required to produce maximum gain or directivity. This new means for studying directivity is not dependent on length or size of the array, as is unfortunately true for earlier techniques which become more difficult with increasing size. From these results, extremely precise information about the directivity-beamwidth product for this design have been obtained.

Another type of array under study at AFCRL for several years is a nonlinear, data-processing antenna, designated the correlation antenna. High resolution is obtained through the use of data processing for correlating the phase relationships of the signal received at the various antenna elements. This antenna permits a significant reduction in the number of array elements needed, compared to the number needed in a conventional linear antenna of comparable performance.

This special type of antenna requires a somewhat more sophisticated understanding of the nature of the propagation medium and antenna target to be studied than has been necessary for more conventional, linear antennas. During the reporting period, it was shown that the correlation antenna is of great value in the study of partially coherent distributed signal sources. Such sources are characterized by a degree of phase correlation between distant points in the source that ranges between complete coherence and complete incoherence. The correlation antenna, inasmuch as a correlation operation between signals received at various parts of its aperture is intrinsic to its design, has great possibilities for the measurement of the coherence properties of a source, with the further possibility that its identification may be determined thereby. There also appears to be a use for these antennas in ionospheric scatter systems, as well as in the study of multipath propagation.

RADIATION PROPERTIES OF ANTENNAS: Several significant theoretical research results of the Laboratory during the period relate to antenna power patterns. The antenna power pattern is simply the distribution of power (gain) within the antenna beam as a function of angle from the center of the beam and distance from the antenna.

Of the several studies on antenna radiation properties, one of unusual interest is a method for processing antenna data to provide increased resolution. The only requirement for using this method is that the antenna power pattern be known and that the sources are not coherent. The latter requirement is always satisfied in radio astronomy and is often met in radar. Resolution is a function of many things —wavelength, antenna size and antenna configuration being basic factors. But,



Experimental model of a multiple-correlation antenna array is shown. The associated nonlinear receiver circuitry permits a significant reduction in the number of elements ordinarily required in a linear array.

quite apart from these, there is another which has nothing to do with the parameters of a particular antenna. This has to do with what the antenna "sees." What the antenna sees is a distribution of targets of varying amplitudes—or more technically, a set of spatial frequencies. The spatially distributed frequencies can be considered by Fourier analysis to be a set of sinusoidal variations in space, of specific amplitude and frequency. The technique uses the properties of incoherent source distributions to extend the spatial frequency content of the collected radiation beyond the antenna cutoff. Unlike methods of extrapolation or analytic continuation, this technique actually enhances information content in the presence of error or noise. The unique method involves the computer solution of an iterative equation.

A long-standing antenna research goal is that of synthesizing a desired power pattern without constraints on the far field phase. Another study provides an optimum solution to this problem. In this study, the antenna response is characterized by a transfer function. The transfer function concept, widely used in optics, specifies which spatial frequency components in the object spectrum will be passed by the antenna and how much distortion each component will incur as it passes through the system. A defining equation is used which minimizes the error between the desired transfer function and a realizable transfer function to be synthesized. The results are obtained without regard for the far field phase.

Several other studies, relating to coherence properties, were of note. One concerns a simple mathematical technique for determining radiation properties of a partially coherent aperture. It involves the convolution of the antenna power pattern with the transform of the coherence function, thereby enabling results to be determined graphically when the power pattern is not easily formulated analytically. The results have been used to compute the diffraction patterns of several planar apertures. The second study shows the applicability of mutual coherence to the most basic of all antenna theorems — pattern multiplication. Some unique results were obtained. For example, in a coherent field, linear in amplitude, the array theorem describes the amplitude. In an incoherent field, linear in power, the array theorem gives the power distribution in the field. In the case of partially coherent illumination, no convenient expression in terms of the array theorem was obtained either for the mutual coherence or for the mutual intensity.

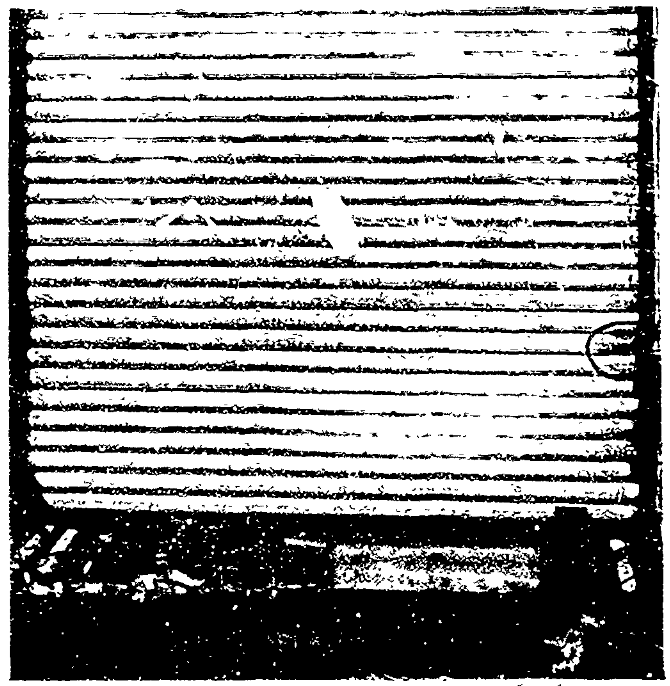
PARTIALLY COHERENT FIELDS AT MICROWAVE FREQUENCIES: An experiment was devised for generating partially-coherent electromagnetic fields at microwave frequencies and for measuring the properties of these fields. In optics, partial coherence can be demonstrated by the Young's interference experiment in which radiation from an extended incoherent source causes interference fringes after passing through two spaced pinholes. The "quality" of these fringes is a measure of the visibility or degree of coherence of the fields at the plane of observation. Although these optical experiments are fundamental in coherence theory, the effect has never before been demonstrated at radio frequencies.

The AFCRL experiment consisted of forming an extended incoherent source of radiation, using the microwave plasma noise generated by a bank of commercial fluorescent tubes. This radiation is detected by a two-horn interferometer and phase-locked radiometer which can measure the visibility of the field directly. Excellent agreement has been obtained between the measured degree of coherence and the van Cittert-Zernicke theorem, which predicts these effects, for circular, rectangular, and grating types of incoherent sources. In addition, the diffraction patterns of apertures which are placed in these partially coherent fields have been measured with satisfactory results.

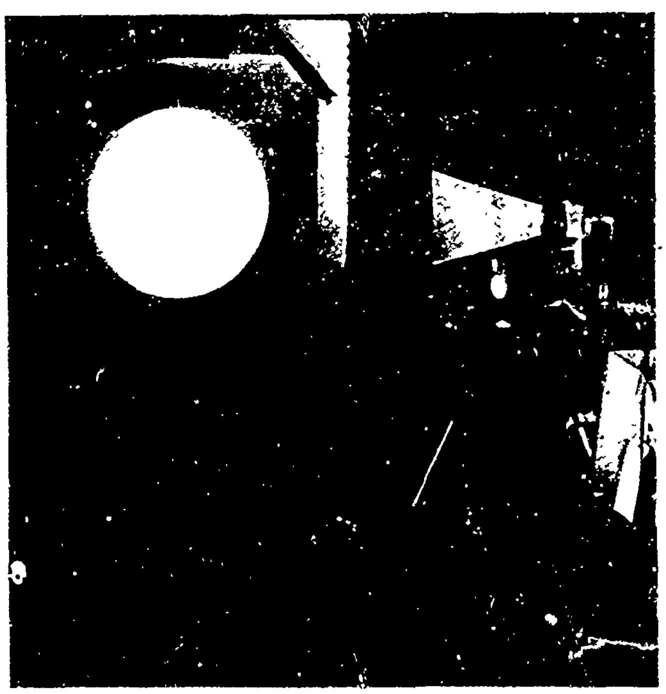
RESOLUTION OF MICROWAVE ANTENNAS: Conventional microwave radar antennas are capable of better performance — better imaging and resolution — than the performance predicted by classical resolution criteria. Antenna designers have known this for some time, but few studies have been undertaken to explain why.

When viewed as a communications theory problem, antenna and optical systems are similar in the sense that the microwave antenna and the optical lens system are both imaging systems in which image quality and resolution are basic considerations. Both can be treated as low pass spatial frequency filters characterized by a transfer function.

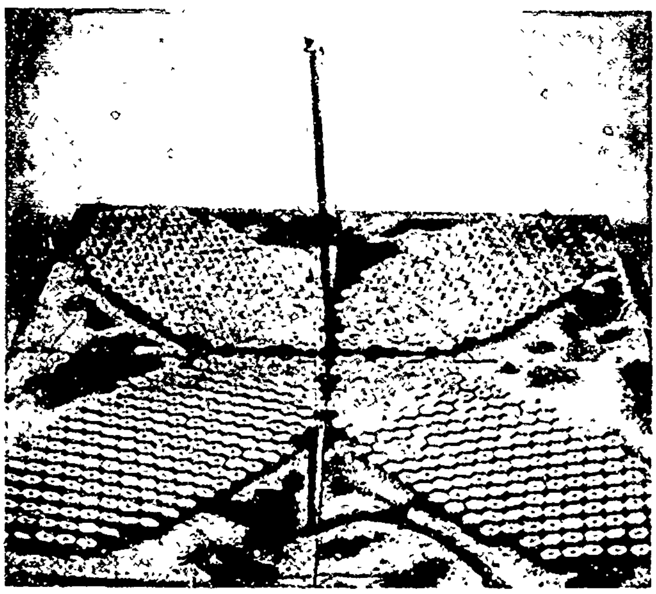
"Spatial" frequency and the transfer function, key aspects of the AFCRL analysis, are briefly explained above under, "Radiation Properties of Antennas." Transfer function techniques are used to analyze the mapping of ground targets by an airborne radar. The traditional approach to evaluating antenna resolving power has been based on the Rayleigh two-point criterion, defined in terms of a specific separation between two isolated point targets. This distance also bears a direct relationship to the beamwidth of an antenna. According to this classical criterion, detail



The bank of fluorescent tubes (top) is used as an extended incoherent microwave source. Fluorescent tubes emit these longer waves in addition to shorter waves in the optical region. Radiometric measurements (bottom) of the radiated fields are used to study the properties of partially coherent microwave signals.



sizes in an extended object smaller than this Rayleigh distance will not be reproduced — that is, resolved — by the antenna. In actual mapping operation, however, detail sizes much smaller have been resolved.



Model of AFCRL's proposed multiplate antenna shows relation of the 2200 plates, each 900 square feet in area, to central feed tower. Used as a radio telescope, the antenna would give man his most distant view into space.

The AFCRL investigation indicates that for certain kinds of extended, man-made ground targets — airfields, railroad yards, and military complexes — image quality and resolution can be very much independent of the radiation pattern used to map them. This result is seen quite readily when antenna resolution capabilities are re-examined in terms of the transfer function.

From the standpoint of aerial reconnaissance, all objects in the antenna's field of view other than targets of interest represent so much clutter — or spatial noise. As a part of the AFCRL study, an attempt was made to measure image degradation as a function of the amount, type, frequency content, and spatial extent of various types of spatial noise. An understanding of these relationships may provide a means for prescribing effective radar camouflage measures.

ANTENNA DESIGN

Theory and design are often so closely interrelated that attempts at treating the two separately are not altogether satisfactory. In this section, however, the focus is on specific hardware and its evaluation. Several of the antennas and antenna elements covered in the following paragraphs have long developmental histories. Work was completed on other antennas.

Essentially completed during the period was work on two large high-gain antennas — one now in operation, the other designed and thoroughly tested by means of an experimental model. These two antennas are the 1000-foot Arecibo radio telescope in Puerto Rico, and the half-mile aperture multiplate antenna. The Arecibo radio telescope, built under AFCRL management, and incorporating techniques originating at AFCRL, was placed in operation early in 1964 by Cornell University.

The multiplate antenna concept was thoroughly tested over a two year period, using a model measuring 70 by 120 feet. All essential performance parameters were investigated with results that met or exceeded expectations. In addition, under contracts totalling more than a quarter million dollars, all relevant engineering for the design of an operational antenna was carried out.

The operational antenna would consist of some 2200 individual hexagonal plates, each 900 square feet in area. It is designed for deep space communications and detection. During the year, a large number of briefings were made to many DOD and NASA groups on the potential performance of this facility. Pending future funding, AFCRL's work on the antenna is completed. The experimental model was dismantled in December, 1964.

"SHORT BACKFIRE" ANTENNA: In an achievement of first-order magnitude, an antenna based on an entirely new principle and promising major advantages in cost and size was developed and tested. This antenna has been named the "short backfire" antenna. It has marked advantages in simplicity over large antenna arrays and parabolas used in satellite tracking networks. Its future role in such networks is expected to be a major one.

This antenna is an outgrowth of work on the "backfire" antenna described in the previous AFCRL Report on Research. The backfire antenna has a resolution twice that obtained by an ordinary Yagi array of equal length. The signal is propagated along an array of dipoles, is reflected from a flat screen and is redirected across the dipole array. Thus, the dipoles serve double duty.

The "short backfire" antenna is seen in the accompanying figure. What it consists of is a flat plate of two-wavelengths diameter, with a circular quarter-wave rim, a dipole feed spaced a quarter-wave in front of the flat plate, and a smaller flat plate spaced another quarter-wave in front of the dipole. The system acts like a partially opened cavity, and produces the remarkable gain of 14.5 db above isotropic, with

At top is a four wavelength backfire antenna having a 23.5 db gain at S band. Below is an array of short backfire antennas with monopulse capability. Gain is 20 db with an antenna depth of ½ wavelength.

sidelobes below 20 db, and a bandwidth comparable to that of the dipole feed itself.

Formed into an array, the short backfire antenna produces the same gain as a dipole or slot array for the same overall aperture area, but with a small fraction of the number of elements required. Thus, a 36-element dipole array, producing about 21 db, can be replaced by a 12-element short backfire array (or, alternatively, by a *single,* backfire antenna four wavelengths long). The element feeds can be circularly (or cross) polarized, and the system as a whole lends itself to monopulse as well as pencil beam operation.

Experimental progress has also been made with the ordinary backfire antenna: sidelobe levels have been reduced to below 20 db, backlobe level to below 30 db, and the gain has been increased by 3 db above the best previously obtained. One such antenna has a gain of 23.5 db above isotropic. This is higher than the gain of a commercial 16-element Yagi array and of a 36-element cavity-backed slot array, both of which are in use as satellite tracking and telemetry antennas.

Although no formal theory of the backfire and the short backfire antenna has as yet been developed, a qualitative explanation does exist. These antennas act like laser cavities, except that the "cavity" (the region between the end mirrors) is filled with air rather than an active medium.

TRICOORDINATE RADAR SYSTEM: Many radar systems for obtaining 3-D information — range, azimuth, and height in a single radar — have been developed over the past decade. These are often unduly complicated — and thus costly. The AFCRL 3-D radar had its beginning about six years ago. Following a long period during which little work was done on it, the Laboratory during the reporting period made further experimental progress with the 3-D antenna and radar.

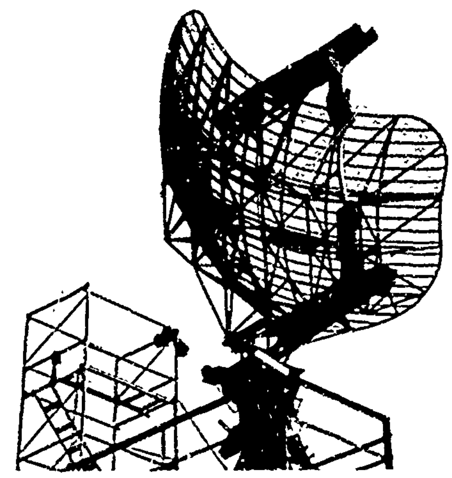
Design simplicity is achieved by using a single feed and a single reflector. The antenna consists of a parabolic torus reflector fed by a line-source feed located in the focal region of the reflector. The feed consists of a circularly curved 15-element slot array. When these slots (radiators) are vertically stacked close to each other, their beams will overlap giving a combined amplitude pattern. The antenna searches in elevation by controlling the phase of the radiations from the slots. Receivers are placed at both ends of the 15-slot array. Energy from a certain angle striking an associated portion of the feed will enter the slots and propagate to the receivers. The signal will arrive with known phase difference that is a function of the angle. Range and azimuth information is obtained in the conventional manner while the antenna is rotating.

A disadvantage of the present radar system is the absence of a moving target indicator (M.T.I.). Therefore, moving targets are difficult to track in the midst of ground clutter. However, the height-finding principle is compatible with conventional M.T.I. and a contractual effort is directed toward incorporation of clutter eliminating circuits for nearby targets in the clutter zone. Overwater operation solves the clutter problem but introduces the problem known as the Lloyd mirror effect, in which the target is doubled because the radar energy is reflected at grazing incidence from the ocean. Present work is concerned with methods for mitigating the Lloyd phenomenon by use of vertical polarization and improved siting.

MONOPOLE AND DIPOLE ARRAYS: Through the application of a new theory and a careful series of measurements, some interesting new properties of monopole and dipole arrays were discovered during the period.

Some of the properties being examined with new theoretical and experimental methods are: self and mutual admittances and conditions under which the mutual couplings may be simplified or reduced; accurate array synthesis procedures for dipole arrays which will give the driving-point admittances; the limitations of conventional theory in describing properties of physically real elements; the possible advantages of using elements greater than a half wave in length; the so-called supergain conditions and when these can be practically achieved; the practical uses of circular arrays with only one driven element; the possible existence of propagating surface wave modes on the circular arrays and the relation of such surface waves to the conventional description of dipole arrays in terms of currents along the radiating elements.

The experimental method being used in these investigations is basically quite conventional but, for any given set of driving conditions, permits a very accurate measurement of the far zone radiated fields, the currents along each radiating element, and the driving-point admittance. In an experimental model, the array elements are monopoles over a 24 x 48-ft. rectangular aluminum groundplane. They are formed by extending the center conductor of a rigid coaxial line through the groundplane. The inner conductor is slotted and fitted with a small balanced loop probe to measure the current standing wave so that below the groundplane the coaxial line serves as a regular slotted line. An auxiliary antenna is located near one corner of the groundplane in the far zone of the array under test. The array under test can be rotated to measure its radiation patterns.



Tricoordinate radar system under test by the Laboratory, using a curved slotted feed, gives range, azimuth and altitude data from a single antenna structure.

Results obtained to date from the investigation of supergaining indicate that when a pair of dipoles are driven to produce either a bidirectional or a unidirectional endfire pattern, the directivity and power gain increases as spacing between the elements is decreased. The maximum increase in gain from quarter-wave spacing is about 1-1.5 db, and is independent of dipole length for lengths not greater than one wavelength. A somewhat different approach indicates that for circular arrays with one driven element, a pattern can be obtained which is dependent only on the total array circumference, independent of the number of array elements, and largely independent of their length. The power gain, however, increases as the number of elements is increased. Further results indicate that when the elements of a circular array are closely spaced, the high reactive fields are due to the self-susceptance and only one or two of the adjacent mutuals.

The interaction of EM energy with monopoles set on a ground plane is complex and very difficult to predict. An infinite variety of monopole configurations and resultant couplings are possible. Here a simple, circular three-monopole configuration is shown.

Circular arrays of dipoles exhibit some interesting properties which are characteristic of the array as a unit. For example, there are "resonant spacings" at which the self and mutual conductances are all at or near maximum values, and at which the self and mutual susceptances are all zero or have very small values. For arrays of 10 or 20 elements, the mutual conductances all have essentially the same value at the first resonant spacings. Generally, the resonant spacings are to be avoided in designing an array because all of the parameters are changing rapidly with frequency near these spacings.

NEW FEED FOR SPHERICAL ANTENNAS: A new type line source phased array was developed by the Laboratory. Although the development is most directly applicable to the recently completed Arecibo radio telescope in Puerto Rico, the technique can be applied to any large-aperture, spherical antenna. The feed system is not intended as a replacement for the present Arecibo line source feed, but as a supplemental feed for operation at the 1420-Mcps hydrogen line frequency.

Since a spherical reflector does not have a single focal point (in contrast to a conventional paraboloidal antenna), it cannot be efficiently illuminated with a point source feed. Work at AFCRL on the focusing properties of spherical reflectors dates back to 1950. It has been shown that rays reflected from a spherical reflector focus along a line and that the effects of this spherical aberration can be minimized by properly controlling the phase along a line source feed. Large, fixed spherical antennas have one great advantage over a comparable paraboloidal antenna — they can be scanned over a much larger angle.

The new feed is 27.72 feet in length and is designed to operate at 2840 Mcps. By simply doubling its length, it can be scaled for the hydrogen line frequency. It consists of an array of 247 pairs of monopoles coupled to a rectangular waveguide. The phase velocity along most of the line source is controlled by tapering the waveguide width.

At the beginning of the line source feed, a phase velocity approaching that of free space is required and this is obtained by using a slow periodic structure of cylindrical posts. The amplitude distribution across the spherical reflector is controlled by the monopole penetration into the waveguide. The advantage of this design is that amplitude and phase can be adjusted precisely, and efficient illumination of the spherical reflector can be achieved.

Other schemes for aberrations corrections are discussed in the following paragraphs.

This monopole-driven phased array was developed for use with large spherical reflectors of the type employed in the Arecibo Radio Telescope. The monopole array has advantages in cost and simplicity over slotted line-source feeds used for correcting spherical aberrations.

ABERRATION CORRECTION: Aberrations — whether in an optical lens or an antenna reflector — occur whenever the system fails to bring rays into complete focus. As seen in the foregoing paragraphs, aberrations are basic to spherical antennas and must be corrected.

During the reporting period, AFCRL investigated a system for correcting aberrations using five feed horns. Placement of the feed is critical. The point above the reflector where the rays converge can be thought of as representing a series of diffraction rings, of the type seen when light is projected through a small opening against a screen. These rings are known as Airy disks. In the AFCRL study, one central horn was placed so as to cover the central Airy disk, the other four horns were placed symetrically around the second Airy disk. These horns were then connected with the proper phase and amplitudes. With this technique the first sidelobes were drastically reduced.

As a part of this work, a detailed study was made under contract of the distribution of the energy in a focal plane or surface. This distribution, of course, tells where the small feeds should be located to obtain minimum aberrations. These feeds must not only have proper phase and amplitude relationships, but proper polarization relationships as well.

The multiple feed array has application to rapid antenna scanning. Rapid scanning of large dishes is difficult because of antenna mass. The technique of feed arrays makes possible rapid electronic scanning or compound scanning of both the dish and feed for overall rapid scanning. As a beam is scanned, each one of these feeds must be properly adjusted for the new scan angle. This scanning can be done by physically moving the feed package, adjusting the individual feed parameters, or a combination of both.

The technique also provides a solution to problems of antenna distortions. Reflector distortions are usually of two types: one is the gross distortion caused by such things as dish twisting under its own weight; the other is the random imperfection of the dish. Preliminary work indicates that gross errors may be partially compensated by controlling the phases and amplitudes of this array of feeds. This result could make possible large cost savings in the building of some antennas. This cost savings can be achieved through the reduction of required rigidity of the dish.

ULTRASTABLE RADIOMETER: Masers or parametric amplifiers are now standard components in radiometers — that is, in the receiving systems of large antennas. But the big jump in sensitivity provided by these new amplifiers has not been achieved without cost. The cost is a continuous, unpredictable drift in gain. Unless the equipment is closely monitored, there is no way of knowing whether the variation in the strength of the recorded signal is real or is due to the equipment.

The gain drift problem in radiometers has been eliminated in a new type of radiometer designed by the Laboratory. This radiometer has proved to be extremely stable. This stability is achieved by a very simple principle. A motor-driven variable attenuator is used to continuously vary a reference noise source in order to balance the incoming noise signal. In this way, gain drift effects in the active components of the radiometer are eliminated.

The absolute stability permits the radiometer to be operated automatically. It can be turned on and off with a time clock. In the particular model built and evaluated by the Laboratory, it has not been necessary to calibrate the radiometer except when components are changed. These advantages can result in a great saving in manhours used to monitor the radiometer and process the data.

The radiometer was used in a test program associated with AFCRL's experimental multiplate antenna. The reliability of the radiometer data has speeded up this testing program significantly. Few patterns were lost due to radiometer failures and it was not necessary to make large numbers of patterns to insure data reliability.

MICROWAVE PHONONS

Microwave phonons are essentially acoustic waves, or mechanical vibrations of a crystal lattice, having frequencies in the microwave region. Investigation in the microwave phonon area now constitutes a rapidly expanding segment of electronics research. AFCRL has made significant contributions to this new field of research.

One reason for the AFCRL emphasis is the high potential for payoff in Air Force equipments and devices. Equipments include radar, radio transmitters and receivers, and computers. Devices include delay lines, isolators, switches, attenuators, phase shifters, circulators, amplifiers and oscillators. Some of these may eventually employ entirely phonon modes in place of EM modes now used.

Research is an essential precursor to this hardware. At the research level the concern is mainly with the generation, detection and interaction of microwave phonons. These considerations in turn involve studies of piezoelectric or magnetostrictive coupling, anharmonic lattice forces, spin wave interactions, and external coupling circuits. One of the hopes of this research is that ultimately the existing low conversion efficiency from microwaves to phonons may be raised essentially to unity.

Phonons can be generated in a variety of ways by the use of both piezoelectric and magnetostrictive materials and, as recently demonstrated at AFCRL, even by the use of nonmagnetic, nonpiezoelectric materials. For the generation to occur, it is obvious that a coupling mechanism between the EM waves incident on the sample crystal and the normal modes of vibration of the crystal lattice must exist. The coupling may be direct, as in the case of phonon generation by the microwave electric field at the surfaces of piezoelectric quartz. Or, it may be indirect as when spin waves, fundamental magnetic modes of a ferromagnetic solid, are first excited by the microwave magnetic field and then deliver some of their energy to the phonon modes.

Finally, it should be mentioned that the external coupling circuits themselves are of vital importance in the generation and detection of phonons. A vast improvement in conversion efficiency has recently been achieved at Stanford, under AFCRL contract, by the use of high dielectric constant microwave cavities as coupling circuits. A technique for temperature stabilizing such cavities has been worked out at AFCRL.

Salient among AFCRL's contributions to microwave phonon research have been the generation of microwave phonons by magnetic films, the harmonic generation of phonons in quartz, optical contact bonding of transmission media, and the above-mentioned generation in nonpiezoelectric media and the temperature stabilization of dielectric cavities. Also, research has gone on in the use of parallel pumping techniques for non-linear excitation of spin waves. These techniques have been shown by AFCRL to offer promise for controlling spin wave (and any associated phonon) propagation directions in yttrium iron garnet (YIG) rods as well as offering a technique for measuring magnetoelastic constants in a variety of ferromagnetic substances. The magnetoelastic constants characterize the coupling between the spin wave and phonon modes of the system.

Phonons are generated in a variety of ways, one of these being indirect by means of the Laboratory equipments shown here in which spin waves are excited in a magnetic field and deliver some of their energy to phonon modes.

PHONON GENERATION IN MAGNETIC FILMS: Thin magnetic metal films have been under intensive study for many years — but only recently have they been used for phonon generation purposes. The first detailed study of magnetic thin film transducers was published in 1963 by AFCRL. The basic principle involved in this kind of transduction is the conversion of magnetic spin wave energy into degenerate frequency elastic wave energy through the mechanism of magnetostriction.

At Stanford University, under AFCRL contract, the magnetic film technique was combined with the dielectric cavity technique to produce the highest known conversion efficiency from microwaves to phonons—18 db at 9 gc at room temperature. The dielectric cavity enabled the exciting microwave magnetic field to be amplified over twenty times its usual value for an air filled cavity. Thus, upon biasing to ferromagnetic resonance, a still greater percentage of the incident EM energy could be directed into the magnetic film sample than in the absence of the dielectric cavity.

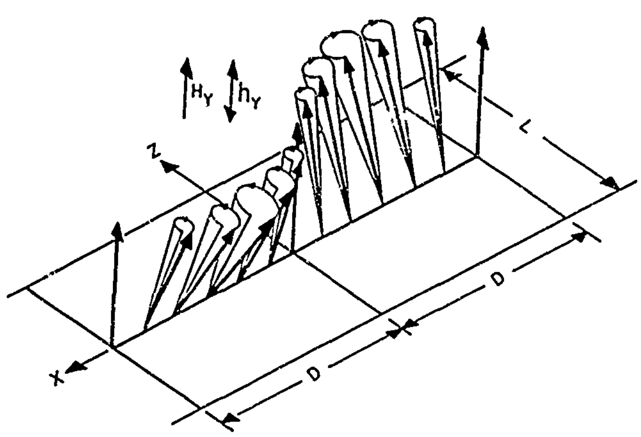


Illustration shows probable resonance mode in a "Stripe" domain of width D in a magnetic film of thickness L. Phonons are launched in the Z-direction and can be generated even when the biasing magnetic field, H_Y, is nearly zero.

Recent work at AFCRL has resulted in the discovery of phonon generation by a new kind of domain wall resonance in the thin films. This process greatly extends the usefulness of film as phonon generators since now both longitudinally and transversely polarized phonons can be generated without changing the external magnetic field configuration. More important, phonons can be generated in a zero magnetic field—a fact which should enable the magnetic film phonon generation technique to be conveniently extended into the upper microwave frequency realm.

It has been established at AFCRL that the longitudinal modes are generated by the domain walls while the transverse modes are generated by the usual ferromagnetic resonance. The domain walls are called "stripe" domains and were very recently discovered in permalloy films by Japanese workers. AFCRL was quick to utilize this discovery and showed that the new phonon generation must originate in such "stripes." The precessional spin motion responsible for the generation is illustrated schematically in an accompanying diagram. Such a precessional mode is rather unique among ferromagnetic resonance phenomena and the phonon coupling to this mode is undergoing further study at AFCRL.

At the Franklin Institute, under AFCRL contract, extremely narrow stripe domains (about 300 A° width) have been observed in AFCRL-supplied samples by the use of a refined surface replica technique. Further studies of stripe domains at the Franklin Institute are being carried out in conjunction with AFCRL in order to gain more understanding of the phonon generation mechanism in the stripes.

HARMONIC PHONON GENERATION: One way to generate increasingly higher frequencies is to extract the harmonics of a lower frequency. Frequency is doubled by extracting the second harmonic, tripled by extracting the third. AFCRL has demonstrated that it is possible to extract both the second and third harmonics of microwave phonons in quartz.

The AFCRL experiments are conducted at liquid helium temperature. This is done in order to avoid the heavy attenuation of microwave phonons which exists at room temperature. The attenuation itself, however, constitutes the very mechanism by which the phonon harmonics are generated; it is the phonon-phonon interaction or scattering caused by the anharmonic lattice forces which produces the harmonics by means of energy and momentum conservation of the phonons. If the attenuation is too great, however, no signal at all gets through the quartz rod.

The experimental apparatus is in the accompanying figure. A quartz rod is connected between two microwave cavities, one at the fundamental frequency (3 gc or 4.5 gc) and the other at the harmonic frequency (9 gc). The fundamental frequency acoustic wave generated by the external EM power delivered to the cavity, produces the second or third harmonic phonons at the quartz rod surface or in its volume. The harmonic wave impinges on the opposite end of the quartz rod, is converted to EM power and detected.

The harmonic power output is at present quite low — of the order of microwatts. However, the important thing is that the principle has been demonstrated. Conversion efficiency can be improved by already existing techniques as well as by future research. Also, the effect allows the measurement of certain anharmonic crystal lattice constants and such measurements are now being performed in quartz at AFCRL for the first time.

BONDING TECHNIQUES: To make use of phonon generation techniques in devices or in research on new materials, low-loss acoustic bonds between various media are needed. Bonds made by conventional techniques are extremely lossy at microwave frequencies. Only about one percent of the acoustic power is transmitted across the bond. AFCRL has developed a new bonding technique which is based on the fact that two highly polished materials will cling together. The term "optical contact bond" is given the technique because the thickness of the bond is measured in terms of the wavelength of light. The thickness of the AFCRL bond is at most one-twentieth of the wavelength of light. Using optical contact bonding, AFCRL has demonstrated experimentally that microwave phonons can be transmitted between two materials with bond losses of less than one percent.

When two optically polished surfaces are cleaned and pressed together under high vacuum, they will adhere. Photo shows a heavy glass disk suspended from a thin quartz rod, demonstrating the strength of these bonds. This technique makes possible for the first time a low-loss microwave acoustic bond.

Another bonding approach is to evaporate a thin film of magnetic or piezoelectric material directly onto the substance to be studied. A new thin film generation technique, the use of piezoelectric cadmium sulphide thin layers, has been pioneered by Westinghouse under AFCRL contract. These films are comparable to magnetic films in conversion efficiency. Techniques for multiple-layering of such films, currently under study at Stanford University under AFCRL contract, offer great promise for improvement in conversion efficiency.

Another solution of the problem would be to find a physical process or mechanism by which microwave phonons may be directly generated in an arbitrary material. It has been demonstrated at AFCRL that the radiation pressure or force exerted by the electromagnetic field on any material can be used to generate microwave phonons. The process at present is not very efficient, but again the principle has been demonstrated and a new class of experiments has been shown feasible.

TEMPERATURE STABILIZATION OF DIELECTRIC CAVITIES: It has been mentioned previously that high dielectric constant cavities greatly improve the conversion from microwave to phonons. A necessary concomitant of this high energy storage capacity is the generation of large amounts of heat in the dielectric crystal. Thus the temperature can change rapidly under operating conditions and the resonance frequency will tend to shift. At AFCRL the dielectric cavity was placed in close contact with boron nitride and this enabled the heat to flow out of the crystal rapidly enough to stabilize the temperature. This is significant since one of the drawbacks to the use of dielectric cavities has been their limitations to room temperature use.

PARALLEL PUMPING STUDIES: The parallel pumping technique, by which a selected spin wave can be driven unstable and directly observed, has contributed greatly to our understanding of relaxation processes in ferromagnetic insulators. In the past AFCRL has made careful measurements of the magnetoelastic (spin wave to phonon) interaction in YIG. This work has been extended to a study of the dependence of spin wave propagation direction on magnetic field in YIG. This dependence is directly attributable to magnetic anisotrophy in the YIG and a careful comparison of theory and experiment has been made at AFCRL. The information is being used in an attempt to gain actual control over the propagation direction of spin waves in YIG rods.

Under contract, another application of the non-linear pumping technique has been made offering obvious device possibilities. A mixture of spin waves and phonon waves, called magnetoelastic waves, has been set up in a YIG rod by an inhomogeneous field gradient and then amplified by the pump field. The process, which actually has an efficiency of *greater* than one since it is microwaves that are amplified, makes possible electronically tunable microwave delay lines and also avoids the use of acoustic bonds since only one YIG rod is needed.

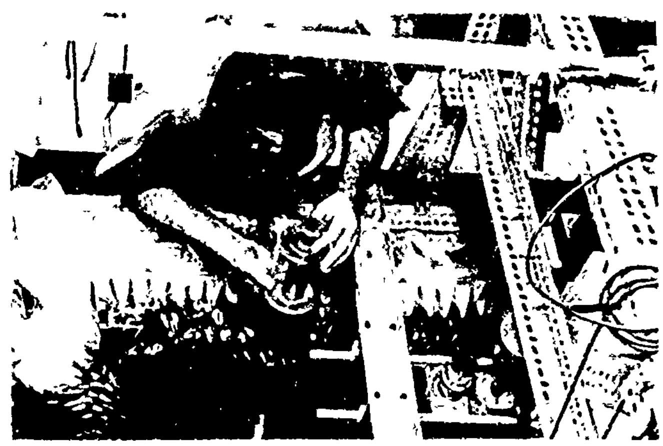
The non-linear growth of spin waves in parallel pumping experiments is an extremely complicated phenomenon since the spin wave interactions are not quantitatively well-understood at the higher power levels. Under another contract, a systematic study of the growth of the spin wave population is being undertaken in an attempt to gain new understanding of spin waves at high power levels.

The detailed analysis of spin wave anisotropy and magnetoelastic interactions at AFCRL has been made possible because of the development of a system for automatically plotting spin wave instability thresholds. Done manually, the plotting of these thresholds is tedious and time consuming, requiring about eight man-hours for each of the many plots required. Further, the manual method is often inaccurate and subject to error. With the automatic plotting system, the time required to plot each curve has been reduced by a factor of more than ten, and the possibility of skipping over or misinterpreting irregularities has been eliminated. Recently, further improvements in the automatic plotting scheme which make it even more versatile have been achieved at AFCRL. The automatic plotting technique is now being used to study magnetoelastic effects and measure magnetoelastic constants in a variety of rare-earth substituted ferrimagnetic garnet materials.

PROPAGATION THROUGH PLASMA

When the plasma research program was initiated several years ago, emphasis was placed almost exclusively on the problem of propagating a signal through the plasma sheath that surrounds a vehicle nose cone during reentry into the atmosphere. This work led, of necessity, into the analysis of the fundamental physical processes which occur when radio waves interact with highly ionized gases. "Highly" ionized gases is a qualitative term. What, for example, distinguishes "highly" ionized gases from "relatively highly" ionized gases? The problem then, if it is to be fully illuminated, is not one limited to propagation through the ionized gas of the plasma sheath. It encompasses all aspects of wave propagation through plasma media.

Seen in this light, the plasma sheath problem becomes merely a special case of a more broadly defined problem. Simple communications between the earth and satellites in which the signal must pass through the plasma layer of the ionosphere, radar studies of auroral echoes, radar probing of the solar corona and photosphere are some of the practical situations where it is necessary to study the effects of plasmas on radio propagation.



The plasma environment is simulated by means of this oil-filled tank. The radiating source (antenna) is first placed in a volume of air before immersion in the oil bath, thus separating the antenna by an air gap to simulate negative dielectric constant.

EM ALTERATION OF PLASMA MEDIA: A plasma medium may be altered when electromagnetic waves propagate through it. Just how much it is altered and in what way depends on the power level of the signal, the frequency, the plasma density, and the collision frequency. But this was previously understood only in a qualitative, empirical way. Rigorous analytical studies of physical processes had not been made until recently. Of extraordinary significance, therefore, were theoretical investigations completed during the period on the effects of EM energy on plasmas.

The AFCRL theoretical research program is concerned with the response of plasma media to radio frequency waves of moderate and high field intensities under a wide range of plasma parameters. Unlike ordinary dielectrics, the effective dielectric constant of a plasma can be altered by field strengths of relatively moderate intensity. AFCRL studies show that many things affect the reflection and transmission coefficients of an inhomogeneous plasma: (1) scale of electron density gradients; 2) scale of electron temperature gradients; 3) thickness of the medium; 4) initial degree of ionization and 5) relative magnitudes of the electron-neutral, electron-ion and electron-electron collision frequencies. Theoretical results show that for a plasma corresponding to high temperature air (5000° K) subjected to X-band radiation, 10 to 20 percent changes in reflection and transmission coefficient will occur as the incident field intensity is increased up to a certain critical field intensity. Above this critical field intensity (which is a function of the frequency of the incident wave), the electron temperature, under steady state conditions, will become very large with a consequent large increase in electron density. This will result in a sharp drop in transmitted field intensity and a sharp increase in reflected energy.

These theoretical investigations involve the simultaneous solution of the Boltzmann equation and Maxwell's field equations. The Boltzmann equation governs the behavior of the electron velocity distribution function, which is determined by the electromagnetic field intensity, elastic and inelastic electron-neutral and electron-ion collisions, electron-electron collisions (self-collisions) and by the temperature and density gradients present in the plasma. The velocity moments of the Boltzmann equation determine the behavior of the microscopic variables, such as temperature, density, current flow, heat flow and particle flow. The transport coefficients—such as electrical and thermal conductivity, and particle diffusion coefficient—may be calculated once the velocity distribution function of the plasma is determined. When a plasma is subjected to electric fields of moderate and high intensities, the electron distribution function and the transport coefficients become functions of the impressed field intensities, and the problem becomes more complex.

One interesting result of the analysis is that at moderate field intensities, the boundaries defining plasma media can be altered in such a way that an initial electron density profile will appear to move toward the perturbing source of electromagnetic radiation.

For the case of a monochromatic, transverse plane wave incident upon an inhomogeneous plasma which varies slowly in space and time, the coupled system of Maxwell's equations and the moments of the Boltzmann equation may be solved numerically. The results of these studies show that: 1) even though the electron energy relaxation time is much longer than the period of the electromagnetic field, the plasma temperature may not reach a steady state because the boundaries defining the plasma medium may move under the perturbing influence of the electromagnetic wave; 2) the wave field in the plasma will not remain monochromatic even though the incident wave is monochromatic because the electrical conductivity is time varying; 3) the time scales for electron density and electron temperature changes may be vastly different, and can be drastically changed as the incident flux level is changed.

Theoretical studies are also being conducted on nonlinear wave propagation in inhomogeneous, anisotropic plasmas. Results of these studies show that, when an elliptically polarized plane wave is normally incident upon a plasma slab, only two distinct modes will exist in the inhomogeneous, anisotropic plasma slab when the electron density gradients are parallel to the direction of a dc magnetic field and both are perpendicular to the interfaces of the slab. In the weakly ionized case, the electron distribution function will be non-Maxwellian, and the form of the distribution function will depend upon how the energy is split up into the right and left circularly polarized components of an elliptically polarized wave.

Hence, the medium is polarization sensitive. At high power levels, the propagation characteristics of the right circularly polarized mode will depend upon the presence of the left mode, and vice-versa, so that the two distinct modes are coupled. Using numerical methods, it is possible to compute the net reflection and transmission coefficients for the right and left modes corresponding to an elliptically polarized wave incident upon an inhomogeneous, anisotropic, nonlinear plasma slab for a wide range of dimensionalized plasma parameters.

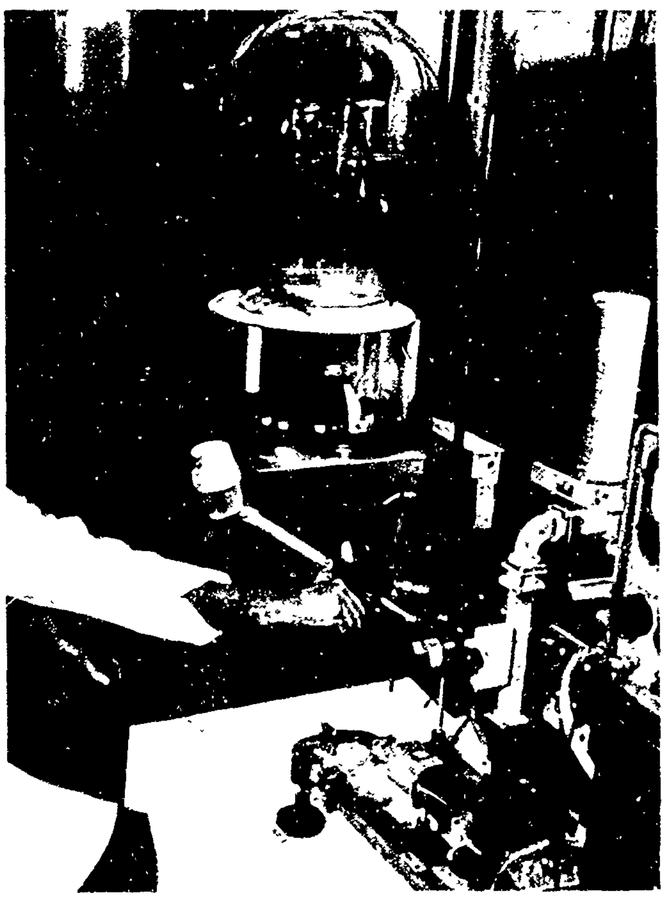
Other theoretical studies are concerned with electron diffusion and heat flow as a function of temperature gradients and density within the plasma, and the dispersion of pulsed radio waves by plasma. With respect to the latter, the radio signal will become distorted. In transmitting information through a plasma, such distortions are undesirable, but may be quite useful as a diagnostic tool if fully understood.

In the following sections, a number of experiments directly related to the foregoing theoretical studies are covered.

EXPERIMENTAL STUDIES: To verify the foregoing theoretical work, several experiments are now planned. One involves measuring the electron energy relaxation time in high-temperature (5000° K) gases through the use of a dc arc jet. Gases selected include oxygen, nitrogen, argon and air at 1-50 torr. Microwave radiation at S-band frequencies will be used to selectively heat the electrons. A different S-band frequency at a lower power level will be used to measure the effective cross section of the plasma jet and will detect changes in the cross section due to the changing collision frequency as the electron temperature is perturbed by the second S-band signal. This experiment is essentially a Luxembourg type experiment performed on high temperature gases. It will provide information on inelastic electron-neutral collision processes in gases at temperatures which are normally encountered behind a strong shock wave.

At the conclusion of the reporting period a second experiment was being performed under contract at the G. E. Space Sciences Laboratory. This experiment concerns the time-dependent response of plasmas subjected to moderate and high power microwave radiation. Plasmas will be created by ultraviolet radiation and by high-temperature shock waves. The behavior of an electron density profile perturbed by an intense electromagnetic field will be studied, as a function of time. The theoretical study discussed in the previous section predicts that the electron density profile will move toward the radio frequency source. This experiment will provide a check on AFCRL theoretical calculations.

INTERACTIONS IN OXYGEN PLASMAS: Another investigation was concerned with altering the electron production and loss rates by absorption of electromagnetic energy. The technique of gyromodulation of two microwave signals in a decaying plasma is used. Plasma was placed within a magnetic field so that conditions of electron cyclotron resonance at a particular applied frequency are fulfilled, in this case a 5.30 gc signal with a magnetic field of 1.88 kilogauss.



Plasma is formed around an antenna inside the glass globe to enable scientists to measure radio attenuation at various plasma concentrations.

The applied electromagnetic energy is resonantly absorbed and affects the plasma energy content and hence alters the electron production and loss processes. These changes may be monitored by a second low power probing microwave signal of different frequency. Experiments were conducted in oxygen plasmas at pressures less than 0.2 torr, and with input powers up to one watt. Some results were: 1) cyclotron resonance absorption of moderately low amplitude microwave power (about 100 mw) enhances the electron energy sufficiently to increase the attachment rate of electrons to neutral oxygen molecules; 2) absorption of higher amplitude signals (less than 1000 mw) rapidly enhances the electron energy and provides a mechanism for detachment of electrons from negative ions, and 3) visible light intensity emitted by the "heated" plasma showed that the maximum interaction between resonant microwave signal and the plasma occurs in only a small region adjacent to the point of signal application.

The experiment may be useful in determining the various rate coefficients in ionospheric layers.

Microwave interaction with decaying magnetoplasmas has been used to investigate the attachment coefficient of electrons to oxygen molecules. The discharge tube is made long to minimize diffusion effects in the axial direction. Radial diffusion is minimized by the application of a 2 kilogauss magnetic field parallel to the discharge tube axis. Calculations show that a two-body attachment should be the dominating loss mechanism with this magnetic field for oxygen plasmas of from 0.05 to 10 torr pressure and an electron concentration of about 7.5 x 10^9 electrons/cm^3. An S-band microwave cavity is used to determine electron number density as a function of time in pulsed dc oxygen magnetoplasmas over a pressure range of 0.05 to 3 torr.

PLASMA SIMULATION: The plasma physicist is confronted with somewhat the same problem that confronts the meteorologist in that it is difficult to reconstruct the environment for measurement within the Laboratory. In measuring actual plasmas, interference with container walls limits the validity of the results, and characteristic plasma inhomogeneities are difficult to reconstruct. Nevertheless, AFCRL has steadily refined plasma simulation techniques over the past several years. Plasma simulation can be achieved by constructing a medium of grids of fine wire placed between a radio source and a detector. More recently, the Laboratory has investigated dielectric simulators since the radiation pattern and impedance characteristics of a dielectric-clad antenna depend on the ratio of the dielectric constants of the dielectric sheath and the surrounding media and not on their absolute values. The environmental and electrical conditions are correct for the simulation of a plasma layer if the sheath layer is composed of a real dielectric with a dielectric constant less than that of the surrounding media.

Radiation patterns of a thin axial slit on a cylinder have been taken and the impedance of the slit measured to test this simulation technique. These experimental patterns have been compared with excellent agreement to the theoretical characteristics of a similar slit on a cylinder covered by a plasma layer. More sophisticated methods of plasma simulation are being investigated in order to accommodate more complicated antenna types and simulate more complex environmental conditions.

Another approach to plasma simulation is through the design of appropriate band pass filters. A plasma exhibits the properties of a high pass filter for which the plasma frequency corresponds to the cutoff frequency. Although most simulation techniques cannot duplicate the inhomogeneity of real plasmas, tee section filters with electrical tapers are especially suited for this purpose. The resistive elements of the filters can be varied to simulate the varying absorption properties of a plasma.

A filter network of forty sections, which is electrically one wavelength long, has been completed and will be used to study transient phenomena, such as the frequency dispersion of pulses. Two hundred sections, or five wavelengths of line, will eventually be constructed.

PLASMA SHEATH TESTS: Beginning in 1965, effects of the plasma sheath on communication systems will be measured during reentry to find techniques for improving the transmission and reception of radio signals from aerospace vehicles in the critical terminal portion of flight. Plasma characteristics, antenna pattern distortion, impedance mismatch, attenuation, voltage breakdown, nonlinear effects and several other parameters relevant to transmission through the plasma sheath will be studied in a series of six rocket flights.

At present two payloads have been instrumented and will be launched in 1965-6 to measure antenna pattern distortion, antenna impedance mismatch, and high-power radio signal attenuation at X-band and S-band frequencies. Two more experimental payloads for radiometric noise measurements have

Nose cone and antennas to be used for a reentry communications test onboard a Trailblazer II vehicle are shown. Flight test will be conducted from Wallops Island in the latter part of 1965.

been partially assembled. Each vehicle will carry a special X-band PPM telemetry system operating above the plasma frequency, where signals are only slightly attenuated, to insure complete transmission of all the data during the terminal portion of the flight.

All experiments will be carried aboard Trailblazer II vehicles, four-stage solid-fuel rockets in which the last two stages are fired vertically downwards with reentry velocities of 18,000 feet per sec. The test period of about 15 seconds will be between 350,000- and 150,000-foot altitude.

ANTENNA BREAKDOWN: Antennas on high-altitude vehicles are subject to antenna breakdown which is an undesirable phenomenon caused by the acceleration of electrons by electric fields about an antenna to velocities which produce ionization and conduction of the atmospheric gases. This discharge causes a decrease in radiated power, signal distortion, radiation pattern distortion, and a change in the input impedance of the antenna. At low pressures (high altitudes) the power required to produce breakdown at very high frequencies is low, often only 2 to 3 watts.

Three Nike-Cajun rockets will be flown to altitudes above 300,000 feet to test antenna breakdown phenomena. Transmitters in each rocket will produce breakdown of a 259.7 Mcps quadraloop antenna and a 9380 Mcps narrow slot antenna. The first vehicle was launched in April 1965 with excellent flight data being obtained. These results will be correlated with both wind tunnel and bell jar measurements to determine the accuracy with which the breakdown characteristics of rocket antennas can be predicted from static and dynamic laboratory measurements. The last two launches are scheduled for October 1965.

COMMUNICATIONS

All of the research discussed in this chapter — antennas, microwave phonons, plasmas — are germane to communications and communications equipment. This generalization might be expanded to include not only the research of the Microwave Physics Laboratory, but almost all of the work at AFCRL. Studies covered in this section are directly concerned with communications in the ELF, VLF and millimeter wave regions of the electromagnetic spectrum.

PROPAGATION THROUGH THE EARTH'S CRUST: The prospect of propagating VLF radio signals through rock strata within the earth's crust has great appeal to those concerned with military communications. The advantages of such a propagation path are fairly clear: low vulnerability to bomb damage, high security, and low ambient noise level.

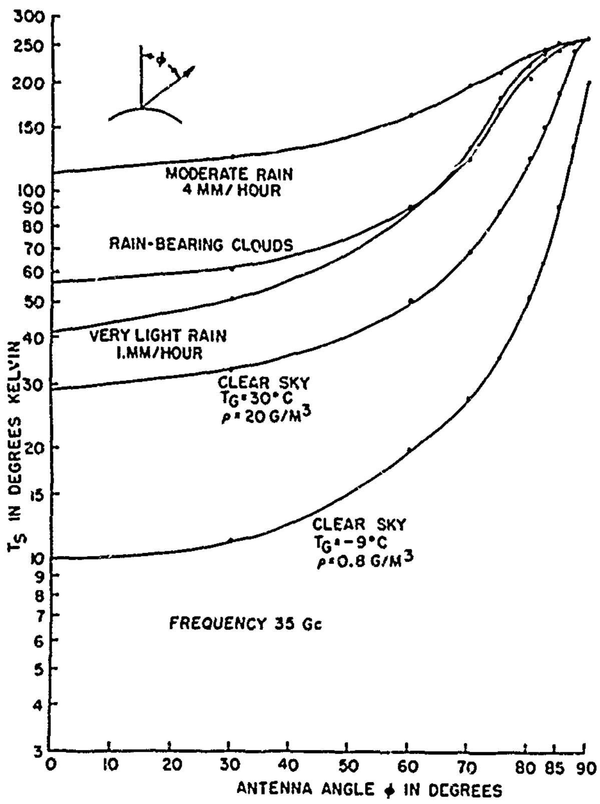
AFCRL's 29-foot millimeter wave antenna located atop Prospect Hill, Waltham, Mass., is one of the most accurate and sensitive antennas ever built for communications research at extremely high frequencies.

Several years ago hopes were high that long distance (100 miles or more) underground paths were feasible. Such hopes have now dimmed. But the advantages of extremely hardened communications even over short paths are of military importance in several applications. This fact has led AFCRL to make a detailed study into the potential of the communication technique.

The AFCRL study has concentrated on the geological, geophysical, and electrical properties of the rock structures. Low attenuation of the propagated signal requires high resistivity—and this means that the rocks must be free of moisture. The search for rock strata useful for radio propagation has centered on the pre-Cambrian rocks of the basement complex. These are the very dense, highly resistive (low conductivity) rocks found at surface depths in parts of New England but which reach a depth of more than 25,000 feet in parts of the Southwest.

Most of AFCRL's recent experimental work has been performed in an area of upper New York State underlain by anorthosite rock, a material thought to be as resistive as any to be found in the United States. Radio propagation at frequencies below 5 kc was successful over a 2.8 mile path using drill holes approximately 2,000 feet deep. Severe limitations are placed on longer paths due to the inhomogeneity and relatively low resistivity of the rock augmented by the presence of atmospheric noise at these frequencies. AFCRL has supported propagation research conducted in deep mines located in the mountains of Innsbruck, Austria. Special portable underground receiving equipment using ferrite magnetic loops has been developed for these measurements. AFCRL is also conducting a study program at NORAD headquarters in Colorado to determine the feasibility of establishing a hardened VLF communications link using through-the-rock propagation.

Measurements to determine a resistivity profile of the earth as a function of depth have been conducted at selected areas throughout the United States believed to have representative basement rock resistivities. The highest resistivities that have been found to date are of the order of 10^3 to 10^4 ohm-meters. Resistivities of the order of 10^6 ohm-meters represent the threshold of feasibility in considering the use of subterranean communications beyond a few miles.



The apparent sky temperature along with the noise contribution of the receiver determines the total noise level of a communications system. Typical apparent sky temperatures are plotted above as a function of zenith angle and meteorological conditions.

MILLIMETER COMMUNICATIONS: Millimeter wave propagation studies have the principle objective of earth-space communications. In this application, millimeter wave communications offer several advantages: 1) the availability of large bandwidths; 2) high gain, narrow beamwidth antennas of moderate size and, 3) possibility of secure communications using narrow beamwidths.

Frequencies above X-band have not been used for point-to-point communications at sea level because of relatively high atmospheric attenuation and noise, plus a random, time-variant, path-loss often referred to as "fading." The principal atmospheric effects which produce fading are absorption, refraction and scattering. The degree of attenuation is related in a complex way to atmospheric conditions along the path of propagation. For an earth-to-space communications link, the amount of the lower atmosphere traversed decreases as the vehicle approaches zenith so atmospheric effects become less severe.

To obtain information on earth-space propagation, either a source, receiver, or reflector must be positioned above the earth's atmosphere. In this study, radio stars serve as sources and the moon as a reflector.

The program itself is centered around a recently installed 29-foot precision paraboloidal antenna designed to operate at 35 gc. The antenna has an advanced radiometric system including a traveling-wave maser preamplifier. The extremely low noise characteristics of the receiver combined with the high gain and precise pointing accuracy of the antenna provide a capability for very weak signal detection. The antenna will also be operated in a radar mode so that attenuation and backscatter measurements can be made using the moon as a reflector. The antenna will be capable of tracking all celestial bodies and, with some limitations, aircraft, rockets, and satellites.

During the reporting period, apparent sky temperatures were measured on a daily basis at 15, 17, and 35 gc. From these data it is possible to predict the sky noise contribution to the antenna temperature as a function of antenna pointing angle and meteorological conditions. The temperature of the sun, near zenith, has also been measured on a daily basis at 15 and 35 gc, and found to be relatively constant, thereby making it suitable as a reference source.

MICROPULSATIONS: Micropulsations are natural background noise found in the ELF spectrum between .01 and 5 cps. This background noise is being studied for several reasons. Comparatively little is known of the details of the natural signals at ELF. Any use of ELF for communication purposes will require a thorough knowledge of the background noise. This noise does not appear to be random in nature but consists rather of oscillations at discrete but varying frequencies. These oscillations may be caused by resonances of the earth-magnetosphere system, by the filter effect of the magnetosphere and ionosphere, or by solar energy packets impinging on the earth. The study of the ELF signals will also shed light on the composition and processes of the magnetosphere and outer ionosphere.

The present program is concentrated on the study of natural ELF signals at four widely separated stations in Maine, Hawaii, Peru and the Philippines. Knowledge of the worldwide simultaneity of the signals and the detailed study of power spectra obtained at the individual locations will add considerably to the understanding of ELF modes.

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IV Space Physics Laboratory

The Space Physics Laboratory conducts research to provide the Air Force with environmental data that may affect manned and unmanned space missions. The research program is also designed to learn more about events originating in space that influence Air Force ground and airborne systems. A basic goal of these investigations is to develop techniques for predicting changes in the near-space environment. A prerequisite to the development of prediction techniques is a better understanding of the space environment and processes taking place in it.

The research program is centered on solar, radio and planetary astronomy, but includes astrophysics, magnetic phenomena, the earth's radiation belts and cosmic ray research. In addition to these space-oriented, observational and theoretical studies, the Laboratory conducts energetics research directed toward finding better ways to generate electric power for space operations and to convert energy from one form to another.

This research, particularly astronomy, requires large facilities. The Laboratory operates two major U. S. observatories: Sacramento Peak Solar Observatory at Sunspot, New Mexico, and Sagamore Hill Radio Observatory at Hamilton, Massachusetts. Two additional facilities, one still in the planning stage, are also part of an expanding program in astronomy. One of these, a 60-inch telescope, has already been completed. It is located in Chile at one of the best "seeing" spots in the world. Its construction was jointly sponsored by AFCRL and the National Science Foundation, and it will be used primarily for stellar astronomy. It is scheduled to become operational in late 1965. The second is a vacuum tower solar telescope, to be located at the Sacramento Observatory. Construction as of July 1965 was awaiting congressional approval. The vacuum tower telescope should improve resolution by a factor of two.

In addition to astronomical instruments, the Laboratory operates two large shock-tubes for plasma physics research, and three vacuum chambers for simulating the lunar environment. The Laboratory is a large user of rockets and satellites. Scores of instrument packages for observing the near-space environment were designed by Laboratory scientists and sent aloft during the period.

The Director of the Sacramento Peak Observatory, Dr. John Evans, is shown here beside the flare patrol telescope and associated equipment in the smaller of the Observatory's two domes.

SACRAMENTO PEAK OBSERVATORY

Since 1952, when it began operations, the Sacramento Peak Observatory has become one of the most productive solar observatories in the world. The 9000-foot peak in Sunspot, New Mexico, on which the Observatory is located, provides the best "seeing" conditions in the country. With its powerful observational equipment, Sacramento Peak conducts a variety of research programs ranging from routine, continuous monitoring of the sun to theoretical studies of the various phenomena that occur on the sun's visible surface and in its atmosphere.

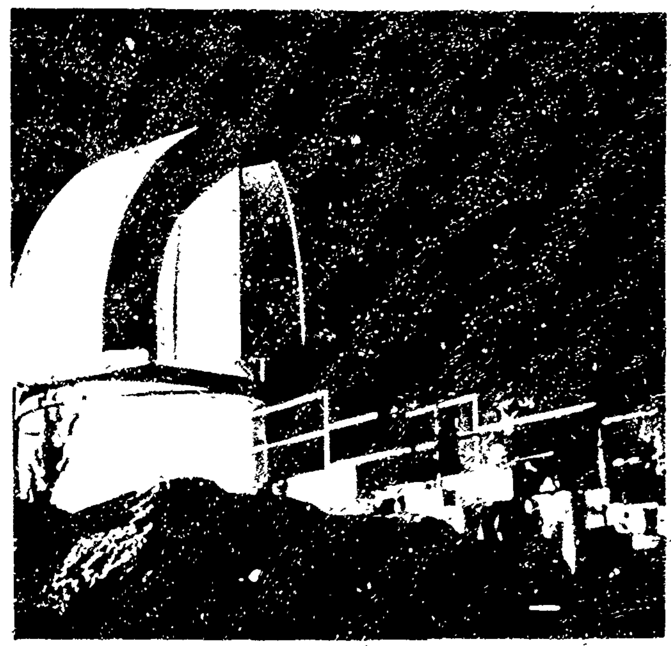
In September 1963, the Observatory undertook a continuous, long-range patrol of sunspot activities, a patrol which will continue through at least one 11-year solar cycle. The purpose of this patrol is to obtain as complete a record as possible of sunspot evolution. To obtain this continuing record of sunspot activity, a small image of the sun in white light is photographed every five minutes through a 16 cm aperture telescope. The extremely fine-grained film used provides high resolution, showing solar granulation and excellent sunspot detail.

The sunspot patrol is part of a larger solar patrol program whose purpose is to record all visible activity on the sun. This program employs a number of telescopes all mounted on a common spar in the smaller and newer of the Observatory's two domes. These instruments are: 1) a 6 cm flare patrol telescope, used to observe flares and other types of activity on the solar disk, 2) a 10 cm spectrocoronagraph for taking spectra of the corona at all positions around the sun's limb, and 3) a 15 cm coronagraph that artificially eclipses the sun so that activity such as prominences and spicules on the limb can be observed. Each of these telescopes is equipped with time-lapse photographic equipment, so that the recorded observations can be played back to show the solar activity greatly accelerated.

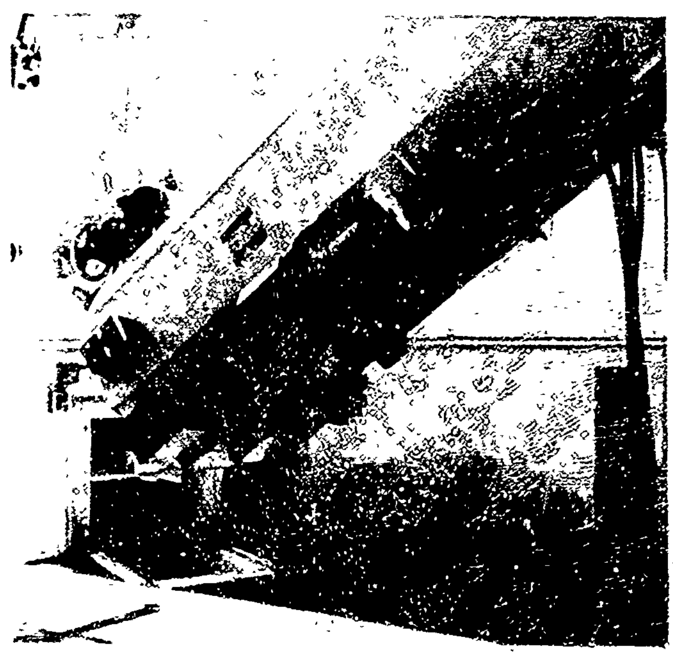
Data from the solar patrol program are reported daily to the World Data Center and the National Bureau of Standards at Boulder, Colorado, for use in prediction of radio propagation conditions. Large flares or other solar activity that may have a pronounced effect on these conditions are reported immediately.

In the larger of the two domes, equipment consists of a 16-inch coronagraph, a 15-inch chromosphere cine telescope, a 16-inch telescope for observing the sun's magnetic fields, and a 9-inch photoelectric coronagraph. During the past two years, several improvements in this instrumentation were made. The speed of the automatic data reduction system was increased from five data points per second to 20 per second. (In this system the output from several instruments is recorded in digital form on cards which can be processed immediately by the Observatory's computer.

During the reporting period, the 16-inch coronagraph was modified by replacing its secondary optical system with elements that are much more transparent to the near ultraviolet. The image quality of the new system is greatly superior to that of the original optics, and some test photographs of solar granulation compare in sharpness of detail to the photographs made from a balloon well above all but a fraction of the earth's atmosphere. A special camera designed and built by observatory scientists takes simultaneous



The dome atop Sacramento Peak in Sunspot, New Mexico, houses the Observatory's flare patrol equipment. This equipment includes a 6 cm telescope shown below with coronagraph and photographic equipment attached. Instrumentation automatically monitors and records all solar activity.



photographs of the sun in the Ha (hydrogen alpha) line and the K (Calcium II ion) line, or in white light. This capability has been invaluable for the study of relationships between spicules and other features on the solar disk.

The sun, the object of this intensive study by Sacramento Peak astronomers, has a diameter of 1.4 million km. At the sun's core a temperature of 14 million degrees K is maintained by a continuous thermonuclear reaction. At the bottom of the photosphere — a layer 300 km thick — where the sun's visible surface begins, the temperature has decreased to 7000 degrees K and further decreases until it reaches a minimum of 4500 degrees K at the top of the photosphere. There, at the beginning of the chromosphere, the temperature again increases until it reaches one to two million degrees at 15,000 km where the corona, the sun's outermost layer, begins.

Prominences and flares originate in the photosphere. Prominences take many forms, but generally they are clouds of low density material which shoot up to heights of 50,000 to 200,000 km. Tremendous energies are needed to produce prominences. The most spectacular of these are giant loops which sometimes occur above active centers. Flares, sudden outbursts of radiation as large as 100,000 km in diameter, are also sometimes produced by active centers. Flares last 20-60 minutes, and sometimes give off the proton showers which constitute a hazard to men and equipment in space. Determining which active centers are likely to produce flares and which flares are likely to produce proton showers is the largest single problem that Sacramento Peak astronomers are trying to solve.

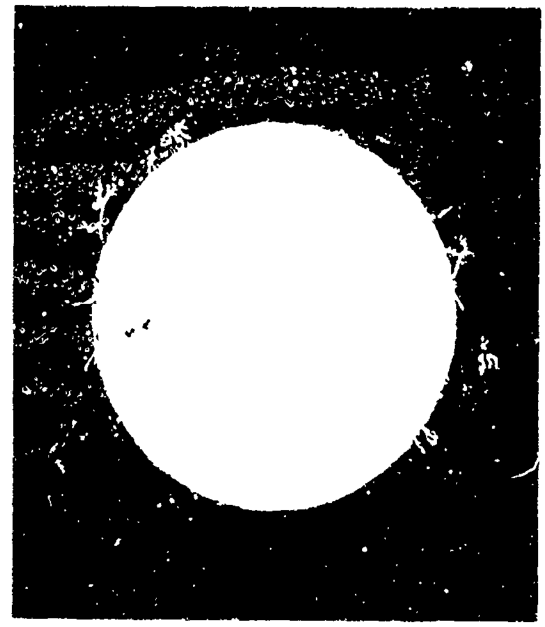
PROTON SHOWER PREDICTION:

Ionizing proton showers erupt intermittently from the sun. The observatory is attempting to predict — up to ten days or more in advance — the safe periods when no proton showers will occur. When a sound basis has been established for predicting the absence of proton showers, a significant hazard to manned space operations will have been reduced.

For these warnings, protons must be detected as they leave the sun. The two known indications of this are large, visible flares, and type IV radio bursts whose relation to proton showers was discovered by radio astronomers at Fort Davis, Texas, working under contract to AFCRL. Short term warnings require a 24-hour-a-day watch on the sun, and plans are being made to secure observations from various solar observatories all over the world.

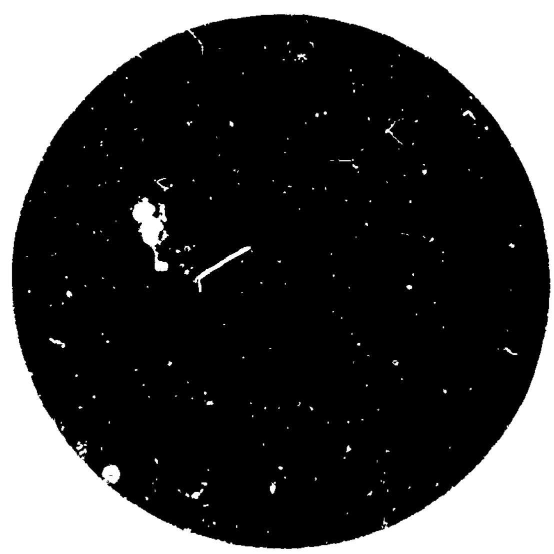
The proposed vacuum tower telescope with its high resolution will be of immense value to the proton shower prediction program. This large telescope will allow observation of the small-scale solar phenomena that play an important role in flare formation. Funding for the Sacramento Peak vacuum tower telescope has been approved by the Air Force, the Department of Defense, and the Budget Bureau, and was awaiting congressional approval as of 30 June 1965. If this approval is forthcoming, construction could begin in late 1965. The telescope will be 325 feet long, 200 feet of its vertical length being underground.

Another instrument which should considerably advance the art of proton shower prediction is the Doppler Zeeman Analyzer (DZA) which was developed at Sacramento Peak and put into operation in the fall of 1964. This instrument allows Observatory astronomers to study the details of magnetic fields in the active centers which give rise to proton showers. Like the conventional Babcock magnetographs used by other observatories to measure solar magnetic fields, the Doppler Zeeman Analyzer makes use of the fact that the Fraunhoffer (or dark absorption) lines of the solar spectrum are split as they pass through magnetic fields of the sun. The degree of this splitting is used to determine the strength and direction of the field. Unlike Babcock magnetographs, however, the Doppler Zeeman Analyzer is not saturated by the magnetic fields of several thousand gauss which spring up in active centers. Its operation does not depend on brightness. This is an extremely useful characteristic, since brightness varies enormously in the sunspot regions of active centers. The Doppler Zeeman Analyzer's accuracy is comparable to that of Babcock magnetographs and it has a sensitivity of $\pm$ 6 gauss for a one second observation of a magnetic field 1500 km square on the sun.



Various types of solar phenomena, including prominences, spicules, and sunspots, are displayed in this engraving made by the astronomer Trouvelot in 1876. His engraving, which incorporates a number of separate observations, shows clearly the variety of different types of prominences.

FLARE RESEARCH: Solar flares provide clues to basic solar processes. In spite of the general scarcity of flares during the 1964-1965 sunspot minimum, much was learned from the study of records of past flares. Sac Peak astronomers have found that all loop prominences are intimately connected with flares, and that a flare with loops is far more likely to emit protons than one without loops. The loops appear, however, several minutes after the flare brightness peak, and their usefulness as predictors of proton showers is limited to the 30 minutes to three hours it normally takes for protons to reach the neighborhood of the earth and moon. It was also found that large



This large solar flare (upper left) was photographed in hydrogen alpha light (6563 angstroms) at the Sacramento Peak Observatory. Such flares frequently rise to maximum brightness in less than five minutes.

surges have a similar relation to proton flares. Both loops and surges are now regarded as a part of the flare phenomenon. When seen at the east limb, they serve warning that flaring regions are about to rotate onto the visible hemisphere of the sun.

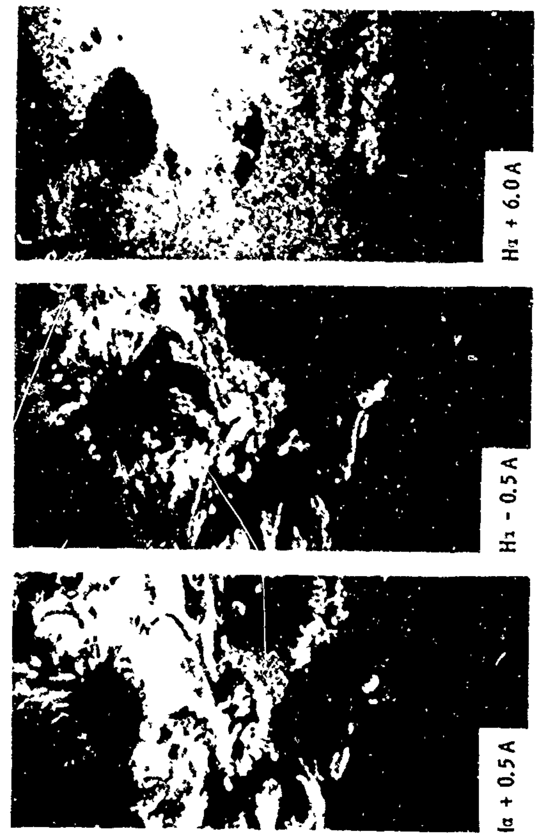
During the period July 1963 - June 1965, the formation and evolution of loop prominences were studied extensively. It is evident that the magnetic fields which confine and guide the loop material must be of the order of tens of gauss. All of the material in a loop strand moves downward from a nucleus at the top into the chromosphere, along two symmetrical arches. This requires a continually replenished source of material at the nucleus. The accepted theory is that the material is condensed from the surrounding corona and cooled by radiation. It is evident from observatory studies that a loop prominence system is embedded in a large region of fairly uniform magnetic field, whose shape is outlined by the downward-flowing streams of loop material. However, the field strength required to constrain the moving loop material if it condensed from the corona would be more than sufficient to prevent the migration of condensing coronal material into the loops in the first place. The improbability of the condensation theory is further shown by an estimate of the quantity of material involved. During its life a large loop system pours a mass into the chromosphere several times the total mass of the corona, but the corona does not appear to be appreciably depleted.

Because of this fact, and through observations of high velocity jet motions at the tops of loops, the Observatory (working with the Joint Institute for Laboratory Astrophysics in Boulder, Colorado) investigated the possibility that material in the form of high energy protons and electrons might be injected into the loops through their "feet" in the chromosphere. Given an adequate acceleration mechanism, the observed behavior of the loops is consistent with this hypothesis. Whatever the acceleration mechanism, it must explain the expulsion of proton showers which the hypothesis predicts would occur if the ejected protons were not trapped in a large magnetic field to form a loop prominence. Thus, according to the hypothesis, a proton shower may be a loop prominence which manages to break away from the sun. It is hoped that a study of the fine structures of magnetic fields in active centers with the Doppler Zeeman Analyzer will clarify the picture.

SPICULES: The study of spicules on the solar limb began at Sacramento Peak in 1956. Spicules are hair-like spikes protruding from the top of the chromosphere. They are generally regarded as ducts conducting mechanical energy from the photosphere through the chromosphere to heat the corona. Observations at the limb provided the basic description of characteristics of individual spicules, but could not show much about their relations to other observable features on the sun.

These relations are now emerging because of a method developed for detecting spicules on the solar disk. Spicules can be seen only on spectroheliograms and filtergrams of exceptionally high resolving power in the Ha (Hydrogen) and K (Ca II) lines. They are tiny elongated dark objects in Ha with bright lower tips in the K line. An ingenious statistical stereo method was used to show that these objects stand up from the solar surface like the spicules at the limb, and occur in the expected numbers. The disk photographs then permit a study of their distribution, which is decidedly non random.

Sacramento Peak astronomers are also studying the relation between vertical velocities in the solar atmosphere, the bright "coarse network" shown in Ha and K spectroheliograms, and local magnetic fields. From these studies, the following picture of spicule formation is emerging. The whole surface of the sun is covered with cells of "super granulation" discovered by Mt. Wilson astronomers. These are roughly circular areas about 30,000 km in diameter within which material at the photosphere is observed to move outward from the center toward the boundary. It was recently found that the moving material wells up at the centers of the cells and sinks downward at their boundaries, as expected. The horizontal motions sweep the small vertical magnetic fields along with the material and deposit them as a magnetic wall along the boundaries. The presence of these fields brightens the K line in the chromosphere, producing the lacy bright calcium network, which coincides with the outlines of the super granulation cells. The network is actually composed of rosettes of spicules, which appear to form a sort of hedge around the super granulation cells, and which occur in regions of concentrated vertical magnetic fields.



The flow of dark matter into a sunspot is suggested by the two lower photographs of this set of three taken at different wavelengths near the hydrogen alpha line. One striking feature of this phenomenon is that the flow, which probably takes place along the outlined channels, stops abruptly at the outer region, or penumbra, of the sunspot.

THERMODYNAMIC EQUILIBRIUM IN THE PHOTOSPHERE: In solar physics, a matter of vigorous controversy is the question of whether or not the photospheric layer can be considered in local thermodynamic equilibrium (LTE). The correct answer makes a great difference in the interpretation of the profiles of absorption lines in the solar spectrum. So far, the argument on both sides has been based on either photographic or photoelectric measurements of line profiles made with conventional spectrographs. These are plagued by serious scattered light effects for which corrections are uncertain. The Observatory's new 13-meter spectrograph eliminates scattered light by means of a double pass system, and the corrections are negligible. At the request of several interested parties of the LTE argument, photoelectric scans were made of the profiles of about 130 lines, selected on the basis of their sensitivity to any departures from LTE at all levels in the photosphere.

Calculations are now being performed which will show whether or not these lines fit the LTE assumption. Although it is unlikely that a single investigation of this sort will be regarded as the final answer, it will certainly provide the weightiest evidence presented so far and point the way to still more critical observations. An early guess is that LTE is a good approximation at low levels and a very poor one near the top of the photosphere, but this is simply Sac Peak's position in the argument.

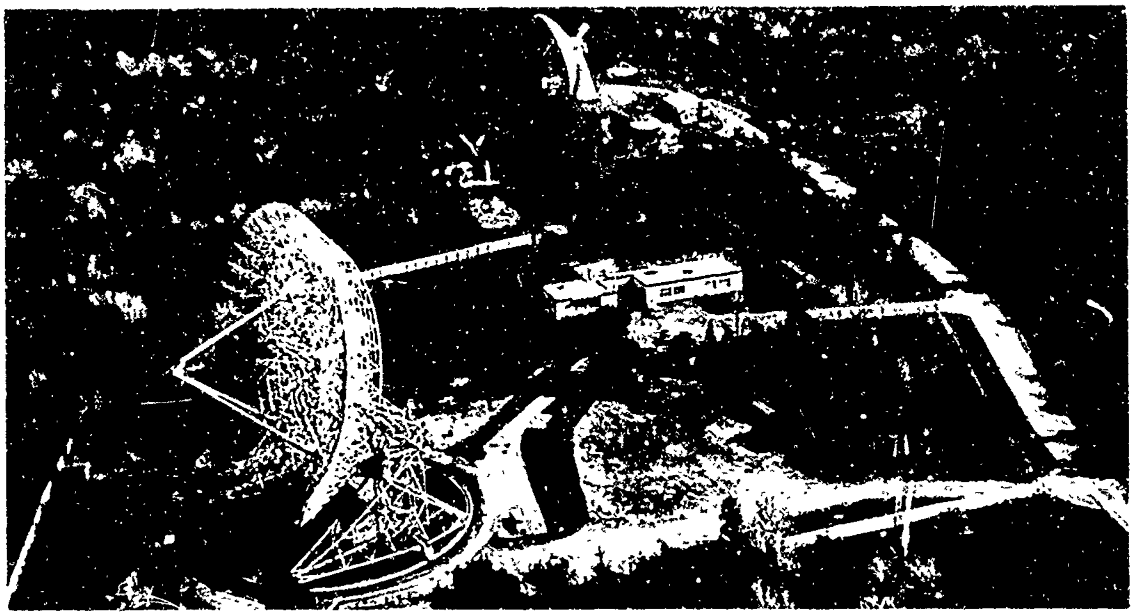
THE DYNAMIC SOLAR ENVIRONMENT: The turbulent, boiling plasma of the sun presents to the astronomer a continuously evolving kaleidoscopic pattern of change. Convections, transfer of energy, plasma interactions with magnetic fields, the random motions and periodic oscillations of the solar atmosphere, are all parts of this pattern. Interpretation of observed phenomena often requires sophisticated inferences, correlations and assumptions.

Astronomers at Sacramento Peak Observatory have a special advantage in their many studies of dynamic solar processes. The high spatial resolution achieved in spectra recorded at Sacramento Peak has not been attained elsewhere. Nearly all the observational material for studies of small-scale motions on the sun are based on Sacramento Peak observations, which are made available to astronomers all over the world.

Most of the studies outlined in the previous AFCRL report continued during this two-year reporting period, with refinements both in data and theory. A more recently observed solar phenomena is one to which the term "spectrum threads" has been applied.

Spectrum threads are longitudinal stripes, parallel to the direction of dispersion, that appear in highly resolved spectra of the bright granules on the sun. In the broad wings on each side of a very strong absorption line, many of the threads are conspicuously curved, with symmetrical displacements perpendicular to dispersion, identical in sign and magnitude on the two sides of the line. In other words, the position on the sun of a bright element as seen in an absorption line is shifted from its position seen in the adjacent continuum. In a given thread, the measured shifts in many lines of diverse strengths show a strict correlation between the line strength and the magnitude of the shift from the continuum position. A typical displacement in a strong line is 500 km. It is known that the height of origin of a line increases with line strength. The observed effect would therefore indicate that the bright element responsible for a thread is a highly inclined column in the solar atmosphere, seen at different heights in the continuum and in lines of various strengths.

This interpretation, though hard to avoid, is difficult to reconcile with the long-established theory of line formation, which requires that the observed 500 km displacements occur in a very thin layer not more than 50 km thick. The established theory also predicts that the top and bottom of this layer should be observationally indistinguishable, and an inclined element would merely produce a smeared thread rather than a cleanly curved one. Either this theory of line absorption is due for serious modification, or some



AFCRL's research in radio astronomy is conducted at this site on Sagamore Hill, Hamilton, Mass. At this site is located the 150-foot alt-azimuth telescope in the foreground, and the 84-foot parabolic dish in the background.

other interpretation of the curved threads must be found. However, if the suggested interpretation is true, the threads will provide a purely geometrical means for ordering the lines of the solar spectrum according to height of origin, without reference to any theories of the solar atmosphere.

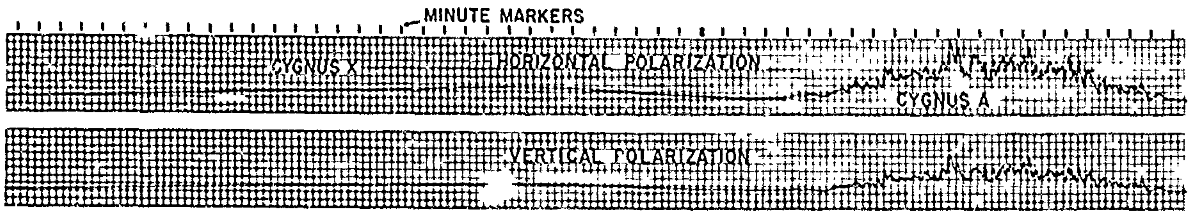
RADIO ASTRONOMY

The radio astronomy program at AFCRL is primarily concerned with radio energy from natural and artificial sources beyond the earth's atmosphere, and the effects of the atmosphere on this energy. The sources of radio energy beyond the earth's atmosphere are the sun, radio stars, satellites, interstellar gases, cosmic background noise, the moon, and planets. Studies of these sources and the atmosphere's effect on them have a bearing on such Air Force missions as communications, detection, navigation, and guidance.

Most of the research is conducted at the Sagamore Hill Radio Observatory in Hamilton, Mass., at 54 degrees geomagnetic north. Here, AFCRL operates an 84-foot equatorially-mounted radio telescope, a 150-foot alt-azimuth radio telescope, an eight-foot solar telescope, three log-periodic antennas and a variety of Yagi and vertical whip antennas.

A new facility for daily radio tracking of the sun will be placed in operation at Sagamore Hill in the first half of 1966. With this facility, high-accuracy flux measurements at 611 Mcps and 1420 Mcps will be made. Further provisions will be made to monitor burst activity. Solar radio activity will be correlated with optical observations of flares. This work is tied in with the proton shower prediction program discussed earlier.

Additional programs consist of sur-



Reception at 228 Mcps from two radio stars, Cygnus X and Cygnus A is shown. Right side of graph shows scintillation (fluctuations in signal amplitude and phase) of Cygnus A. The curve of Cygnus X (left side of graph) is smooth because Cygnus X does not scintillate due to its large diameter.

veys of hydrogen and OH in the region beyond the solar system, and the study of radio noise bursts from the planet Jupiter. Since 1963, AFCRL has taken data on these noise bursts with a view toward learning something of the Jovian ionosphere.

SCINTILLATION STUDIES: The largest single area of study by Sagamore Hill astronomers falls under the category, "scintillation." Scintillations are nothing more than amplitude and phase fluctuations in a radio signal that has passed through the atmosphere.

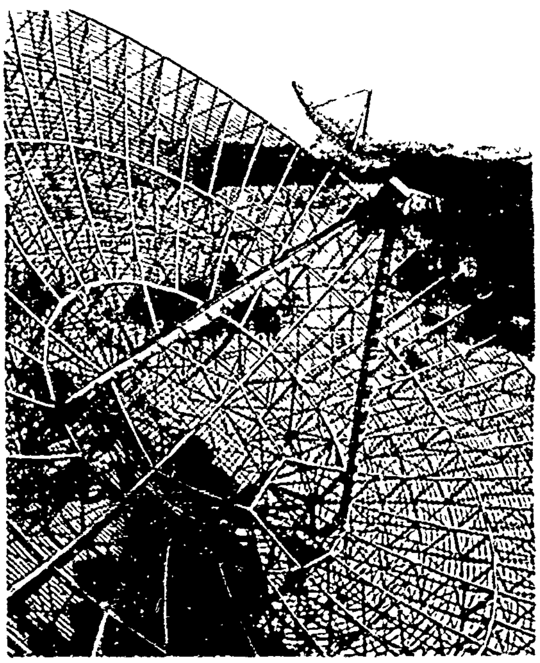
The importance of scintillations to propagation is evident. The fluctuations in amplitude from the lower atmosphere or from the ionosphere can increase signal strengths to several times normal at peak or reduce it to background noise at null. Fast fluctuations of the type observed during auroral displays can produce intermittent loss of satellite telemetry or force an increase in redundancy to transmit the same information. Similarly, scintillation of phase can so change the angle of arrival that directional information is lost. During aurora, the phase deviations have produced inaccuracies in satellite tracking using phase interferometer techniques and in some cases have caused complete loss of signal. This is a serious problem when realtime data must be obtained from satellites.

Observations of two radio stars, Cygnus A and Cassiopeia A, and of two satellites, Cosmos I and Transit IVA, have yielded data on lower and upper atmospheric irregularities. The frequencies studied have included 20, 40 and 54 Mcps for satellite transmissions, and 30 to 3000 Mcps for radio star signals. The irregularities in refractive index in the lower atmosphere produce amplitude fluctuations up to several times average, with a fading rate of 3 to .5 per minute. Upper atmosphere fluctuation rates range from 1 to 60 per minute. Lower atmosphere scintillation rates increase as the elevation angle increases. During intense magnetic storms, the ionospheric scintillation rate increases with wavelength in the VLF frequency range.

Ionospheric irregularities are relatively small — 0.1 to 4 km in diameter. They may be found at altitudes ranging from 100 to 600 km. In the Arctic, they are particularly severe. They constitute the prime factor affecting the level, phase and angle of arrival of signals propagated through the auroral regions.

Space does not permit the treatment of the scores of special and routine observations of scintillation made by AFCRL during the two-year period. There were just too many. Of particular importance is the discovery of the primary role of latitude effects rather than that of angle of elevation, as had previously been thought by English and Australian observers. The published data provide an essential foundation for the optimum design and operation of Air Force communications and radar detection systems.

THE 150-FOOT RADIO TELESCOPE: During the reporting period, the 150-foot radio telescope was made fully rotatable and placed in full operation at the Sagamore Hill Radio Observatory. This telescope is primarily used for studying radio star scintillation and refraction. These studies will lead to a better understanding of irregularities in the structure of the ionosphere's F region. Lunar reflection work at 50 and 220 Mcps was begun in 1965. For better resolution, the 150-foot and the 84-foot telescopes are used together as an interferometer.



Use of Sagamore Hill's 84-foot and 150-foot radio telescopes together as an interferometer greatly increases the resolving power of both instruments.

Daily measurements of the scintillation rate of Cassiopeia were made during the report period with the 150 foot antenna. Four frequencies ranging from 30 Mcps to 220 Mcps were used and a drift was made at the lower transit of Cassiopeia A at 11 degrees of elevation with the 150-foot antenna locked at that elevation. The analysis of the data reveals multiple scattering by aurora almost all of the time at 30 Mcps. The frequency dependence of both the index and the rate is being studied. Analysis indicates that index decreases inversely with the first power of the frequency in the spectral range 30 to 60 Mcps, but that at higher frequencies an inverse square law holds.

ANALYSIS OF SOLAR ECLIPSE: The solar eclipse of 20 July 1963 provided radio astronomers an excellent opportunity to observe radio emissions of the sun's corona without interference from the solar disk itself and to study the effects of the eclipse on the ionosphere. (A similar study was conducted by the Upper Atmosphere Physics Laboratory, Chapter II, with respect to the 30 May 1965 eclipse in the Pacific.)

The 20 July 1963 eclipse was observed at three frequencies — 10,000, 3000 and 1200 Mcps — at field sites both in Maine, which was in the path of the total eclipse, and at Sagamore Hill, Mass., where the eclipse reached about 95 percent totality. Astronomers detected, on the eastern half of the visible disc, a center of radio activity which corresponded to an optical plage, one of the bright regions which surround the darker sunspots. Radio measurements of this center showed that its diameter increases with height in the solar atmosphere above the visible disc of the sun. At 10,000 Mcps, the portion of the center which was high in the chromosphere had an angular diameter of 1.2 minutes of arc. At 3000 Mcps, this diameter was about 1.5 minutes, and at 1200 Mcps in the corona, the region had an angular diameter of 2.5 minutes of arc. The apparent temperature of the region at low heights in the solar atmosphere ranged from 77,000 degrees at 10,000 Mcps to 1,600,000 degrees at 3000 Mcps, and 1,780,000 degrees at 1200 Mcps.

On the basis of these observations, and observations made by other research groups, the spectrum of this region was determined. It seemed to peak between 3330 and 3750 Mcps. The spectrum was compared with spectra of other regions analyzed by the Radio Astronomy Branch and other observatories during earlier eclipses. The spectral index of the region on the high frequency side of the peak was likewise determined and compared with earlier work.

ELECTRON CONTENT OF THE IONOSPHERE: During the solar eclipse of 20 July 1963, AFCRL scientists received a radio signal reflected from the moon to determine changes in the ionosphere's total electron content. Because the moon, during an eclipse, blocks out the solar ultraviolet radiation that maintains ionization, a decrease in electron content was expected. This decrease was observed as a change in the Faraday rotation of the lunar-reflected signals received by the 84-foot telescope at Sagamore Hill. The maximum decrease in electron content, expressed in terms of the electron content of an equivalent vertical column with a cross-sectional area of one square meter, was about 4 x 10^{16} electrons.

Maximum decrease occurred 48 minutes after the eclipse had reached totality. The AFCRL observations were compared with vertical ionosonde and incoherent radar scattering measurements made by scientists of MIT's Lincoln Laboratory. These measurements indicated a maximum decrease of only 2.5 x 10^{16} electrons in an 800 km vertical column. AFCRL scientists feel that this discrepancy between electron content measured by Faraday rotation and that determined by incoherent radar scattering may provide an important clue to the behavior of the ionosphere under disturbing influences.

Since the 20 July eclipse occurred in the afternoon, the AFCRL radio telescope, which was receiving signals reflected from the moon, was not pointed in a vertical direction, while Lincoln Laboratory's radar was. Thus, the discrepancy may indicate that the eclipse had a different effect on different regions of the ionosphere.

EARLY BIRD SATELLITE SIGNALS: In addition to its voice and TV channels, the Early Bird satellite transmitted general "housekeeping" data, such as internal temperatures, on VHF. These VHF telemetry signals from the COMSAT Early Bird satellite have been monitored continuously since 4 May 1965 using the 150-foot antenna. One purpose of this project is to evaluate the propagation problems surrounding the use of synchronous satellites for VHF communications, and in particular for direct communications with Air Force and commercial aircraft on North Atlantic and South Atlantic flights.

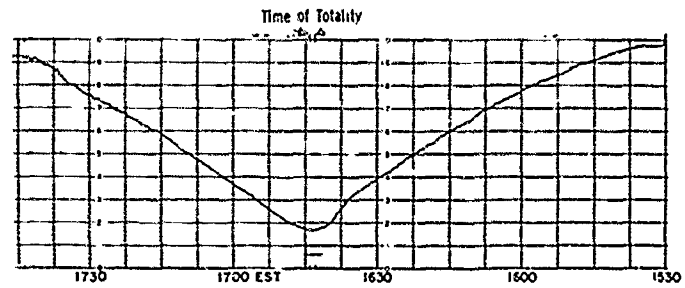
Results on the characteristics of the synchronous satellite's VHF transmissions such as the effective polarization ellipse at middle latitudes, as well as the power output, have been obtained.

The primary goal, however, has been to study the variations of the total electron content between ground level and the satellite as well as amplitude fluctuations of the signal. For a three week period during midsummer 1965, simultaneous measurements were made at AFCRL and at the National Radio Astronomy Observatory, Greenbank, West Virginia, to study latitude dependence of diurnal changes in total electron content. Since the overhead position of the satellite is constant, diurnal variations in total electron content and in amplitude scintillations have been observed directly.

IONOSPHERIC DUCTING: In November 1964, an AFCRL satellite experiment confirmed the hypothesis that a radio signal sometimes becomes trapped between two layers of electrons in the ionosphere. The experiment, known as ORBIS (Orbiting Radio Beacon Ionospheric Satellite), consisted of satellite transmissions at 10 Mcps. Satellite signals from half-way around the world were detected on omni-directional antennas at Sagamore Hill. At a site in Calcutta, the 10 Mcps satellite signal was recorded over a period of 40 minutes. (See Chapter II for a discussion of a related ionospheric ducting experiment.)

This ducting phenomenon has been suspected for a number of years, but could not be fully explored before the ORBIS experiment. Several mechanisms have been proposed to explain it. The simplest of these is the case in which a ray from above or below enters a region of increasing density at a grazing angle. As the ray penetrates farther into the region, it is bent away from the normal and assumes a shallow angle, reaching the earth at a great distance from the expected location. In another and more interesting case, the duct may consist of a region of low electron density bounded on top and bottom by higher density layers. In such a duct, the ray is refracted back and forth between the two high density layers. This zig-zag course is pursued until some nonuniformity in the refraction profile along the duct is reached.

The nonuniformity, or window, permitting the signal to escape could be created by any sharp gradient in electron density. Electron density layers in the ionosphere change markedly from day to night and these changes may also permit escape. It is not necessary that the signal originate from within the ionospheric entrapment channel. Entrapment of a signal could occur if the signal originates from well above the ionosphere or from the ground.



During a solar eclipse, the amount of radio energy received from the sun reaches a minimum at totality. Some residual energy remains, however, because the sun has a larger diameter at radio wavelengths than at visible wavelengths. Unretouched graph shows 10 cm reception during 20 July 1963 eclipse.

OH RADICAL STUDY: In December 1963, AFCRL radio astronomers confirmed Lincoln Laboratory's discovery, two months earlier, of a previously undetected absorption line in the radio spectrum of Cassiopeia A. The new line, at a wavelength of 18 cm, corresponds to the radio absorption wavelength of the hydroxyl (OH) radical.

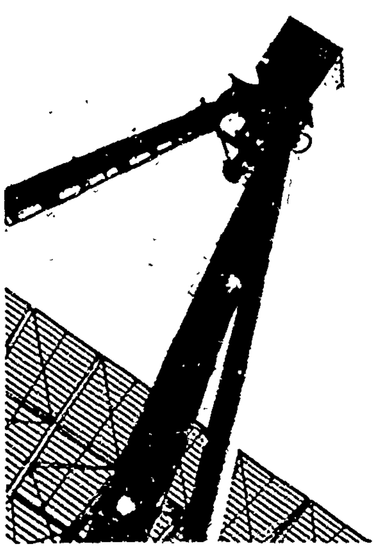
The AFCRL astronomers also detected the hydroxyl line in the spectrum of Sagittarius A, and existence of this line in both radio stars has since been confirmed by other observatories.

This discovery, which indicates that the hydroxyl radical is a constituent of the interstellar gas between the earth and the two radio stars, was one of the most important events in astronomy in 1963. It had previously been thought that interstellar gas was composed almost entirely of atomic hydrogen.

The 18 cm hydroxyl line may take a place of importance in radio astronomy next to that of the well-known 21 cm line of hydrogen. To date, the hydroxyl radical has been detected only in absorption spectra. To produce absorption spectra, the gas must be between a radio star and the radio telescope. The radio star is the source of radio frequencies across a broad spectrum. Each element absorbs certain specific frequencies. This absorption is most pronounced at a wavelength of 21 cm for hydrogen, and 18 cm for the hydroxyl radical.

Both hydrogen atoms and hydroxyl ions in the interstellar gases are moving at very high velocities. Thus their actual absorption lines occur at frequencies which are Doppler-shifted from their rest frequencies of 18 and 21 cm by an amount proportional to their velocities. It is this Doppler shift that enables radio astronomers to discriminate between absorption by interstellar gas and absorption by the earth's atmosphere.

One of the most interesting aspects of the AFCRL observations is that they indicate the presence of hydroxyl radicals where hydrogen is absent. Thus the two gases are not always found in close association. The observations were made with the 84-foot dish at the Sagamore Hill Observatory.



A Parametric amplifier, attached to feed system of AFCRL's 84-foot radio telescope, increased the instrument's sensitivity during AFCRL's OH line studies.

LUNAR AND PLANETARY RESEARCH

The Space Physics Laboratory is studying the age and composition of the lunar surface, the constituents of planetary atmospheres, and the environmental conditions on these bodies. The knowledge is derived largely from spectroscopic techniques, with spectroscopic measurements made in wavelengths ranging from the X-ray region to the infrared. These data are gathered by ground-based telescope observations, and by instruments aboard balloons and rockets.

Laboratory investigations center around three lunar environment simulators — vacuum chambers in which materials likely to be found on the lunar surface are placed for the study of the mechanical and electromagnetic behavior of these materials.

One of the most significant results of the Laboratory's lunar and planetary research during this report period was the discovery of compositional differences among different lunar regions. This discovery, the result of a lengthy and thorough study of infrared reflection spectra of the moon, is described in detail in the following section.

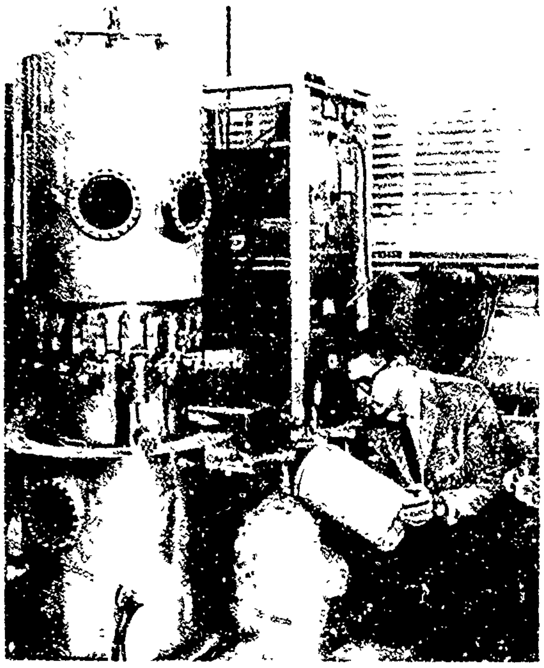
VARIATIONS IN THE MOON'S COMPOSITION: During this reporting period, an apparent difference in mineralogical composition between one region and three others on the moon was measured by AFCRL scientists. This is the first time that such differences in the minerals comprising the lunar surface have been detected, although it has been assumed that the lunar surface, like that of the earth, is not uniform in composition.

The first measurements which showed this difference were made on 26 February 1964, in an infrared spectral region previously unexplored in lunar research, using the 42-inch telescope at Lowell Observatory, Flagstaff, Arizona. The infrared instrumentation was coupled to the telescope, and was designed to cover the 16-24 micron range, where a partial atmospheric window exists. Succeeding observations on 24 separate nights over a period of more than a year were then made to substantiate this discovery.

AFCRL found that the Mare Cognitum, Mare Tranquillitatis, and the floor of the Crater Alphonsus all have a similar composition, but that this composition is entirely different from that of Mare Serenitatis. Since all of the Ranger photographs were of the areas of similar composition, the question arises as to the differences that might be found in an area like Mare Serenitatis. Composition may have no effect on the physical nature of the surface. On the other hand, one explanation of the compositional differences could be that the surfaces photographed by Rangers 7, 8, and 9 were all affected by secondary impacts of debris thrown out of large impact craters formed in material of similar composition, while Serenitatis was unaffected in this way. It is possible that the apparent spectral differences are the result of a marked change in grain size of the surface material from place to place.

Because of atmospheric absorption, features of the lunar infrared spectrum taken from ground-based telescopes become highly obscure. For this reason, AFCRL is planning to send a balloon-borne telescope with a 61 cm aperture to an altitude above all but a fraction of one-percent of the earth's atmosphere — to about 100,000 feet. The balloon-borne telescope project carries the designation, Skytop. Delays have characterized the project. At the conclusion of the reporting, launch was scheduled for August 1965. A successful flight will give clear, unambiguous data on the lunar surface material composition for the first time.

NEW LUNAR ENVIRONMENT CHAMBERS: In March 1964, two new lunar environment chambers, in which temperatures, atmospheric pressures, and radiations comparable to those found at the surface of the moon can be simulated, were placed in operation at AFCRL. The new chambers augmented a similar AFCRL lunar environment chamber that had been in operation at AFCRL since 1962. Designed and built by Varian Associates, the chambers



To simulate the lunar environment and the behavior of various materials in that environment, AFCRL has acquired two ion-pump vacuum chambers (one of which is shown) capable of pressures below 10^{-11} torr. These chambers supplement an earlier vacuum chamber used for lunar simulation work.

can achieve pressures below 10^{-11} torr. Total volume of the working area of each chamber is about 15 cubic feet. A molecular-sieve roughing pump, an ion pump, and a titanium sublimation pump are combined to achieve the ultrahigh vacuums in the chambers. The chambers are being used in a number of studies of materials of the type believed to comprise the lunar surface.

One such study is the observation of the behavior of finely-ground silicate materials at extremely low pressures. Results to date confirm those obtained earlier with the oil diffusion pumped chamber. In a high vacuum, silicate powders show a significant adhesion, indicating that the lunar surface may have a significant bearing strength. Properly designed vehicles should have no trouble traversing such a lunar surface layer.

Studies were made to determine how these high-vacuum adhesive properties of pulverized material likely to cover the moon's surface depend on various parameters such as grainsize and grain irregularities. Although it appears likely that the lunar soil will have a reasonably safe bearing strength, there remains the danger that this soil, if stirred up, might adhere to lenses, portholes and other parts of the spacecraft. Methods of controlling this potential hazard are being sought by AFCRL in a study supported by NASA.

To simulate another aspect of the lunar environment, polished rock and mineral samples of the type likely to be found on the moon were bombarded by a proton beam. Infrared reflection spectra of the samples were made before and after damage by the proton beam which was designed to simulate proton flux on the lunar surface. This study was made to determine whether or not the spectra obtained from the ground and balloons may be interpreted in the light of laboratory spectra obtained from undamaged samples. Results indicate that radiation does not appreciably alter the infrared spectra.

METEOR FLUXES ON THE MOON: Two studies, both involving meteoroid impact on the moon, were carried out during the reporting period.

The first was a study of meteoroid-created lunar craters as a means of interpreting lunar history. The study assumes that older lunar surfaces have more craters of a given size than newer ones. Absolute ages of various lunar surfaces cannot be determined, but relative ages can. By counting craters in the three main maria north of the moon's equator — Mare Frigoris, Mare Imbrium, and Mare Serenitatis — AFCRL scientists found that Mare Frigoris is probably the oldest, and Mare Serenitatis the newest of the maria.

In the second study, Laboratory scientists developed equations which yield the ratio of meteoritic fluxes on the earth to those on the moon, taking into account gravitational attraction and focusing by both the earth and the moon. This ratio can be employed to determine the flux of meteoroids striking the moon. The conclusion drawn from the calculation of these ratios is that the moon may be losing weight, due to meteoroid impacts. Because of the moon's low escape velocity (2.38 km/sec) and its lack of atmospheric drag, more material may be blasted back into space (some of which is captured by the earth) from a meteoroid impact than is gained.

This balloon payload for observing Venus in the infrared was developed by Johns Hopkins University with funding by AFCRL. Two flights of this payload in 1964, both launched from AFCRL's balloon launch facility at Holloman AFB, resulted in the discovery of water vapor and ice crystals in the Venus atmosphere and cloud layer.

THE VENUS ATMOSPHERE: Water vapor in the upper atmosphere of Venus was detected in amounts comparable to those found at the same pressure levels in the earth's upper atmosphere. Evidence that the top of the cloud layer is composed of ice crystals was also obtained. These results are based on experiments conducted for AFCRL by the Johns Hopkins University.

The two balloon-borne experiments which detected these phenomena were launched from AFCRL's balloon facility at Holloman AFB, New Mexico, one in February 1964 and one the following October. Both payloads were carried to altitudes of over 80,000 feet where they were above more than 99 percent of the earth's atmosphere. Measurements of Venus water vapor were made during the February flight, using a 12-inch aperture telescope which automatically locked on Venus for two hours while an infrared spectrometer scanned across the part of the infrared spectrum where absorption by water vapor occurs (around 1.13 microns). For the October flight, the apparatus was modified so that the range of the spectrometer was extended to 3.5 microns, to cover the reflection spectra of ice crystals.

ASTROPHYSICS

Astrophysics is the application of physics to the problems of astronomy. It is concerned with relating a physical model to observations. Most of

AFCRL's research in astrophysics is concerned with describing solar and stellar behavior in terms of plasma physics. The Laboratory's work in this field is both experimental and theoretical. It has as its goal the refinement of knowledge about plasma behavior in itself as well as the use of this knowledge for the solution of astronomical problems.

Of particular interest to AFCRL astrophysicists is the interaction of plasmas with magnetic fields. The sun is a gigantic plasma, and most solar activity — sunspots, prominences, flares — is closely connected with local magnetic activity on the sun's surface. The solar wind is also a plasma, and its interaction with the earth's magnetic field has been a subject of intensive AFCRL study during the past several years. As much as ninety percent of the matter in the universe may be in the form of plasmas and their interaction with magnetic fields in space may play an important role in the evolution of galaxies.

To investigate plasma behavior in the Laboratory, AFCRL astrophysicists have used a number of devices including plasma containment chambers, shock tubes, and exploding wires. These devices are used to investigate plasma turbulence induced by magnetic fields, to simulate the shock wave formed by the interaction of the solar wind with the earth's magnetic field, and to study the rapid transition from the solid to the plasma state of matter.

A number of theoretical studies were concluded during the reporting period. Several of the more interesting of these are covered in the following subsections.

NEW THEORY OF SOLAR ROTATION: The sun rotates faster at the equator than at the poles. This difference in rotation rate, about 25 days per revolution at the solar equator compared to 30 days at the poles, seems to defy basic physical principles, because it implies that angular momentum is being transferred from a region of lower momentum to one of higher momentum. This paradox was resolved in a theory developed by an AFCRL scientist.

According to this theory, momentum is transferred to the solar equator by the same process that maintains the jet stream in the earth's atmosphere. This process is the generation of Rossby waves by temperature differences between the poles and equator of a rotating body such as the earth or sun. (Rossby waves are a form of highly ordered turbulence, arising from the interplay of rotational and convective forces in a liquid or gas.)

Since the visible surface of the sun is a plasma that behaves in many respects like a fluid, sunspots imbedded in it were used to trace the motion of this fluid and determine if it exhibited circulations like Rossby waves. Such circulations, viewed from above, would have a sawtooth-shaped pattern. Indications of such a pattern came from a great many observations of sunspot proper motions — that is, the movements of sunspots independent of solar rotation. Sunspot proper motion has both a north-south, and an east-west component. It was found that, on the average, sunspots moving toward the equator had a higher easterly velocity (velocity in the same direction as the sun's rotation) than sunspots moving away from the equator. This indicated that momentum was indeed being transferred to the equator and lent strong support to the AFCRL theory of solar rotation.

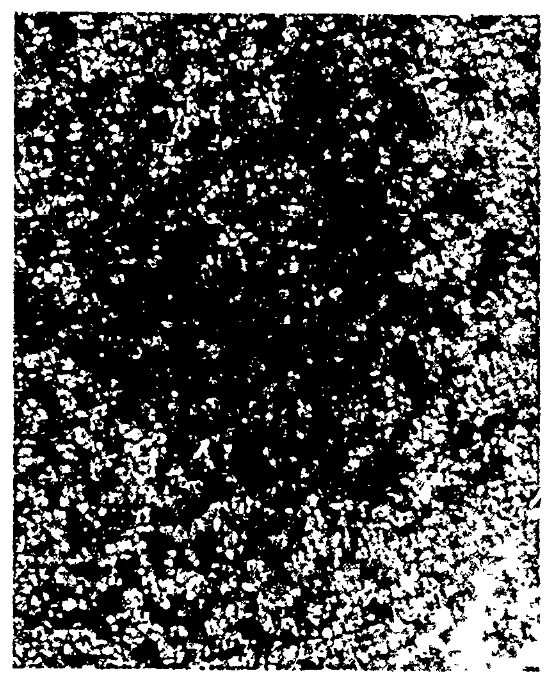
SOLAR WINDS: During the two-year reporting period, another AFCRL scientist calculated the flux of protons and electrons escaping from the sun each second. These particles, which create a constant "solar wind," were first detected by early space probes. According to the theory from which the calculations were made, the protons and electrons in this wind are "boiled" off the sun's corona. The agreement, within an order of magnitude, between theoretical calculations and experimental observations of the solar wind, provides good support for the theory.

Calculations put the loss of solar mass by this process of coronal evaporation at a million tons per second. The material lost by evaporation is replaced by material flowing into the corona from lower regions of the sun.

The theory of coronal evaporation has several important consequences. One of these is that the evaporation process serves as a coronal thermostat. As the corona's temperature (around a million degrees K compared to about 4500 degrees K at the sun's visible surface, the photosphere) increases, more protons and electrons are boiled off. This, in turn, lowers the temperature and the cycle is regenerated. The coronal temperature is thus kept centered around a certain value. The theory also indicates that other stars may emit similar "winds" of protons and electrons. If this process of coronal evaporation occurs in giant stars, which probably have very extensive coronas, it could result in winds of such great intensity that the resulting loss of stellar mass would be high enough to actually affect the evolution of these giant stars. The same process may cause the giants to contribute to galactic X-radiation.

TEMPERATURE OF SOLAR CORONA: Why is the solar corona a million or more degrees hotter than the sun's surface? The core of the sun is kept at several million degrees K by nuclear fusion, but because no fusion takes place in the outer layers of the sun, they become progressively cooler until the excitation temperature reaches 4500 degrees K at the surface. Then temperatures begin to increase, reaching a maximum again in the corona.

One possible key to this mystery is the granulation observed on the sun's surface. This granulation is the only structure normally visible in white light besides sunspots on the sun's disk. Seen through a powerful telescope, the



The sun's surface exhibits a marked granular structure. The grains, with average diameters of 1000 km and lifetimes of three minutes, are believed to be columns of hot material welling up from the sun's interior. As they burst to the surface they could create shock waves which heat the sun's corona to a million degrees as they pass through it.

sun's surface looks like small white grains of rice sprinkled on a grey background. The grains are about 1000 km across and have a visible lifetime of about three minutes. It is believed that these grains are the tops of columns of hot material rising from the sun's interior. As the material in these columns bursts to the surface, it could produce shock waves which heat the corona as they travel through it and expand. Whether or not this mechanism accounts for coronal heating can only be determined by thorough theoretical studies of dissipation mechanisms, wave velocities, and other characteristics of large amplitude waves in a plasma.

COLLISIONLESS SHOCK EXPERIMENT: When the solar wind nears the earth, it interacts with the earth's magnetic field, compressing the field on the side toward the sun, and stretching it out like a tail on the side away from the sun. As a result, there are sharp discontinuities in both the field and the solar plasma wind. The discontinuity on the side toward the sun has all the characteristics of a shock front, or "bow shock" as the solar wind plasma is deflected by the earth's magnetic field. It is, however, a collisionless shock, and this introduces some difficulties into the development of a theory to describe the solar wind-magnetosphere interaction.

To investigate such a collisionless shock in the laboratory, AFCRL scientists built a plasma accelerator that can produce a dense, high-energy plasma. Since April of 1964, solar wind simulation experiments have been performed with this accelerator, and have shed light on what happens when the solar wind interacts with the earth's magnetosphere.

The collisionless shock which occurs when the solar wind impinges on the earth's magnetosphere is simulated at AFCRL. These three high-speed photographs show the formation of the predicted parabolic shock front (seen as the white, curved vertical segment) as plasma strikes a dipole magnetic field.

Particle density in the plasma is about 10^{14} per cubic cm, and particle velocity about 5×10^6 cm per second. In the experiments conducted with the device, a stream of this plasma is directed into the dipole field of a pulsed coil that produces a maximum field strength of 5800 gauss. The result of this interaction is photographed with a high-speed camera.

In the experiments so far, a shock standing off from the coil has been clearly observed. This shock has a well-defined structure, including a parabolic shape predicted by theory. Measurements of perturbations in the dipole field caused by the plasma will be made, and the base pressure of the vacuum system will be improved to prevent stray gas molecules from interfering with the formation of the shock.

PLASMA TURBULENCE: Another Laboratory experiment concerned with plasma and magnetic field interactions began in 1961 when AFCRL designed equipment to study plasma turbulence induced by magnetic fields. Early experiments with this ROMAC (ROtated MAgnetic Cusp) equipment presented a sharp picture of how plasmas move across magnetic fields, and how they rearrange magnetic field lines. During the past two years, Laboratory scientists continued their work with the ROMAC equipment, with emphasis on improving the rise times of the magnetic fields, the degree of plasma ionization, and the accuracy of measurements.

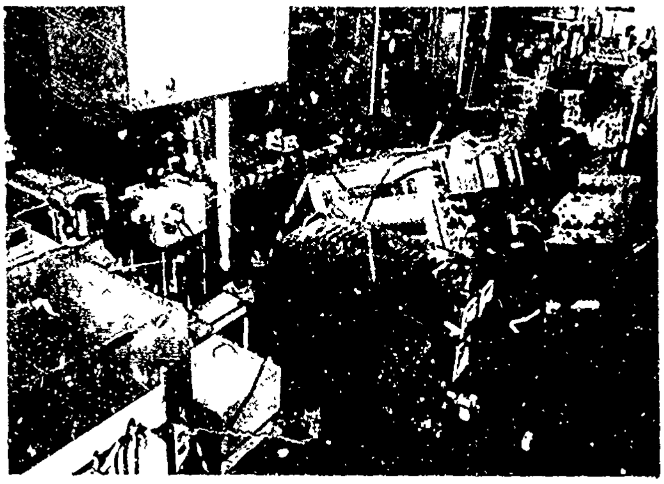
Magnetic fields of two configurations are used in the device. A poloidal or cusp field isolates the plasma from the wall of a doughnut-shaped plasma containment chamber while an axial or toroidal field introduces turbulence into the plasma. The coils producing the fields are energized by the discharge of high-voltage capacitors. The cusp fields last 7 milliseconds and reach 10,000 gauss at the wall. The axial field lasts only 26 microseconds, and plasma lifetimes have been limited to the microsecond range. During an experiment, the plasma is pre-ionized by a radio frequency signal. The coils are then energized, and the subsequent behavior of the plasma is studied. Field measurements are made by probes both inside and outside the chamber and ionization is measured by a light pipe in the chamber.

It has been found that the pre-ionization field decreased 50 percent and the intensity of the light in the chamber decreased by 80 percent when the cusp field came on. Without the cusp field, or with a very weak cusp field, the toroidal field penetrated the plasma and produced increased light emission, indicating that additional ionization had taken place. The toroidal field inside the plasma was considerably distorted. When a strong cusp field was applied, the axial field still penetrated the plasma and was distorted, but produced no additional light emission. No indication of plasma compression showed up when the cusp field was applied, however. Thus it appeared that the cusp field required a faster rise time to compress the plasma.

EXPLODING WIRES: One method of generating a dense, high temperature plasma is by discharging a large amount of electrical energy through a small wire in a very short time. Under this high energy flux, the wire explodes, passing from the solid to the vapor state in a millionth of a second. During this microsecond, however, high-speed instruments, including cameras, can record the wire's rate of expansion, density, and other parameters.

AFCRL is one of the leading laboratories conducting exploding wire research. Since 1959, AFCRL has sponsored three international conferences on exploding wires, the third being in March 1964.

During the past two years, the Laboratory has concentrated on the study of time-space changes in the density of material during the phase change at the peak of the explosion. This study is being carried out in two ways. First, by exploding wires of different sizes and shapes and noting differences in the behavior of their electrical properties (resistance, current, and voltage), AFCRL scientists



Data from experiments with this 20-foot shock tube help AFCRL scientists determine the relative abundance of substances in stars. At the end of the tube (foreground), a battery of instruments, including a new ultrasonic temperature probe, measures various parameters of a gas which has been heated to several thousand degrees by the passage of a shock wave down the tube.

have learned much about how the density of round wires decreases during an explosion. Second, by using X-ray techniques to penetrate the plasma sheath that surrounds the core of the exploding wire, scientists have been able to study physical changes in size and density with an accuracy not attainable by any other means.

Measurements of thickness of exploding round wires by X-ray showed that expansion of the metal takes place in two stages. The first stage is an ordinary thermal expansion caused by ohmic heating of the wire. Radius increases linearly with time. The second stage, which starts suddenly when thermal expansion reaches a maximum, also shows a nearly linear increase of radius with time, but the rate of increase is much faster than in the first stage. The exact nature of the change from the first to the second stage will be studied further.

F-VALUE MEASUREMENTS: Experiments with a 20-foot shock tube are being made to provide the astrophysicist with a firmer basis for interpreting spectral recordings of the sun, stars and nebulae. This study consists of determining the ratios of the absolute spectral line intensities of atoms, ions and molecules to their concentrations. This ratio leads directly to a quantity which spectroscopists call the line's absolute "f-value." Once the absolute f-values for the spectra of a number of substances have been determined, astronomers can find the relative concentrations of these substances in the atmospheres of stars and in nebulae by measuring the absolute intensities of their spectral lines. Such studies can help answer questions concerning the relative abundance of various elements in the universe and how the heavier elements were formed from lighter ones during stellar evolution.

The shock tube used in these experiments is 20 feet long and two inches square. The tube is filled with neon. Absolute f-values of the lines of each substance are measured separately by mixing a small amount of the substance in gaseous form with the neon in the tube. Helium or hydrogen is placed in a pressure tank associated with the tube. At a given pressure, a diaphragm separating the pressure tank and the tube bursts, creating a shock wave in the tube. After shock reflection from the tube's other end, the neon is heated to between 3000 and 15,000 degrees K — the general temperature range at the visible surface of the sun and most of the stars.

The determination of absolute f-values is difficult for several reasons, and temperature is one of them. Not only are spectral line intensities different for each transition in each element, molecule, or ion, but they also vary widely with temperature. The critical role of temperature in these measurements led to the development of a new ultrasonic temperature probe, a development which is important in assuring that the f-values obtained in the shock tube experiments are accurate. Temperature is measured most precisely when the measurements are direct — that is, when the temperature probe interacts with the hot gas itself. There was only one way of doing this (the line reversal method), and researchers have needed a second direct method for cross-referencing.

The ultrasonic temperature probe developed during the period represents a second method. The new probe works on the principle that the speed of a sound through a gas depends in a well-known way on the temperature of the gas. By sending a one-megacycle pulse through the gas and recording the time it takes the pulse to travel through the gas, the gas temperature can be derived. Many attempts have been made by others to apply this principle to the measurement of shock tube temperatures, but without notable success. The difficulty has always been that the high noise level of shock tube operation saturated the detectors. In a recent series of tests, in which measurements were made by both the new ultrasonic probe and the conventional line-reversal method, the temperatures obtained by both agreed very closely.

Although the probe was developed for use in AFCRL's 20-foot shock tube, it can be used with a variety of high temperature devices where gas temperature is a vital parameter. When the sound attenuation is also measured, this ultrasonic probe becomes a powerful new device for measuring the transport properties of gases.

GEOMAGNETISM

The magnetosphere is the volume of space between the "top" of the ionosphere (an arbitrarily defined 1200 km) and the shifting boundary of the magnetopause — that boundary where the solar wind impinges on the magnetic field. The most pronounced and best known features within this volume are the earth's radiation belts. The magnetosphere can be thought of as a viscous, dynamic elastic medium. It is a source of electromagnetic energy detected at the surface of the earth, energy arising in part from hydromagnetic waves propagating in the medium. These waves in turn are set in motion by internal and external stresses — one of these being the pressure of the electrons and protons that comprise the solar wind.

The geomagnetic research program revolves about the study of quasi-static and time-dependent aspects of the earth's magnetic field. The program has both observational and theoretical phases. The observational phase is carried out with rocket- and satellite-borne instruments and at ground sites.

GEOMAGNETIC FLUCTUATIONS: Fluctuations of the earth's geomagnetic field originating in the ionosphere and magnetosphere occur over a broad range of frequencies. The Laboratory has investigated oscillations having frequencies of less than one cycle a minute and others with frequencies up to 50 cycles per second.

Geomagnetic fluctuations in the 1-45 cps range have been correlated with worldwide thunderstorm activity. This correlation was based on magnetometer data taken over a six-month period at Denver.

Four Nike-Apache payloads, including the one above with nose cone removed, were instrumented with cesium vapor magnetometers (mounted at top of rack) to probe the equatorial electrojet, a band of current flowing through the ionosphere near the equator.

It was clear from a comparison of the daily plots of amplitude fluctuations of the six frequency bands monitored that almost all of the magnetic fluctuations observed originated from a common source. It was also found that magnetic intensity fluctuations had a daily pattern quite similar to that of thunderstorm activity, which reaches a maximum in mid-afternoon, tapers off in the evening, and reaches a minimum in the early morning hours (local time).

Amplitude of the fluctuations was greatest in the summer months when thunderstorm activity nearest the Denver site was at a seasonal high. The amplitude of the fluctuations was strongest at a frequency of about 1.5 cps (the lowest of the six octave frequency bands observed) when the thunderstorm activity was within 2000 miles of the receiving site. The data also tended to confirm an earlier hypothesis that the cavity between the earth and the ionosphere can act as a waveguide for certain types of electromagnetic radiation. This was indicated by the fact that the effects of more distant activity occurred at frequencies which corresponded to the resonant modes of the earth-ionosphere cavity.

To study magnetic variations having periods of greater than a minute, a special variable-area recording magnetograph has been designed and several units were in operation during the previous reporting period. Six observing stations extending from polar to equatorial zones were established. These stations are located at Godhaven, Greenland; Kiruna, Sweden; Weston, Massachusetts; Fredericksburg, Virginia, and Huancayo and Cuzco, Peru. This wide geographical distribution permits the study of magnetic variations as a function of latitude.

Processing of data from these six

stations is being done automatically. It involves the electromechanical conversion of the analog type magnetograms to digital data. The data consist of the amplitude and variability of each component of the earth's magnetic field. The data processing procedure represents a considerable advancement in data handling since the customary manual operations are not continuously required in the routine conversion of the photographic analog record into digital data.

Magnetic tape recordings of geomagnetic fluctuations over the frequency range of 0.005 to 50 cps are being made at Concord, Massachusetts; Pt. Barrow, Alaska, and Huancayo, Peru. The tapes, originally recorded at 0.1 inch per second, are played back at various speeds up to 60 inches per second for aural analysis. The result is a weird, music-like "noise" with odd rhythmic patterns. While useful, this is not a quantitative method of analysis. More detailed analysis was made using speech and sound analysis instrumentation. Frequency versus time patterns of selected data samples were made by means of sonagraph and rayspan analyzers. Waveform amplitude and phase studies are made from visicorder records.

A more recent study is the correlation between geomagnetic fluctuations and cosmic noise absorption. Fluctuations over a wider range of periods from about 10 seconds to three hours are being considered in this analysis.

ROCKET-BORNE MAGNETOMETERS: For direct observations of geomagnetic fluctuations in the magnetosphere, two Blue Scout, Jr., rockets, capable of reaching altitudes of 25,000 km were launched from Cape Kennedy — the first in March 1964, the second in January 1965. Instrumentation consisted of multicell alkali-vapor magnetometers. Neither of the flights was fully successful, although some useful data were returned from the peak altitude of about 1000 km reached by the rockets.

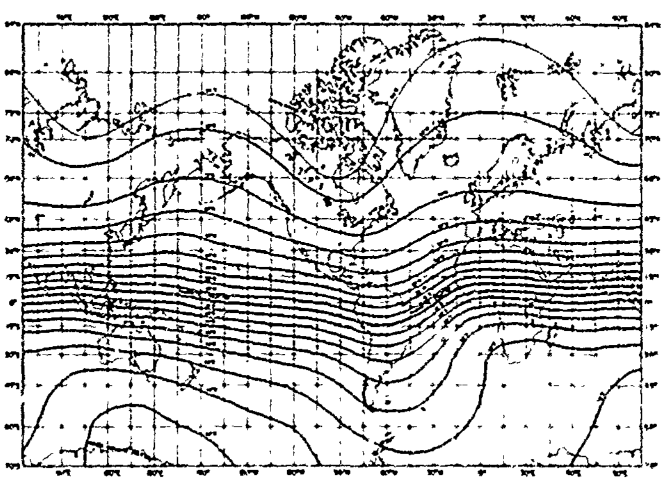
More successful was the launch of four Nike-Apache rockets from an aircraft carrier at the magnetic equator off the coast of Peru in March 1965. These rockets were instrumented with alkali-vapor magnetometers to measure the equatorial electrojet — its height, thickness, intensity and latitudinal distribution. The equatorial electrojet is a band of east-west flowing current, about 660 km wide, centered over the magnetic (dip) equator. Its presence was first inferred from the variation in the horizontal component of the magnetic field as measured at the earth's surface.

The rocket payloads were designed to minimize the effects of spurious magnetic fields near the sensor unit. All ferro-magnetic materials were essentially eliminated, and fiberglass racks and nose-cone covers were substituted for aluminum ones to prevent stray fields due to eddy currents that might otherwise be induced in a conductor spinning in the earth's magnetic field. The magnetometer employed cesium vapor as the working fluid with an output signal of approximately 3.5 cycles per gamma. This was used to modulate the telemetry carrier directly so that the ultimate accuracy attainable in this experiment was more a function of rocket-position indeterminancy than of instrumental error.

THE MAGNETIC EQUATOR: Several parameters can be used to define magnetic equators. Two of the most common criteria are: 1) the locus of points where the magnetic lines of force are parallel to the earth's surface (the magnetic dip equator), and 2) the best simple dipole fit to the earth's field obtained from a spherical harmonic analysis of measurements from all over the earth's surface (the geomagnetic or dipole equator). From this it is seen that the position of the "equator" varies, depending on the parameter used to define it.

During the period July 1963 - June 1965, Laboratory scientists studied how the position of a number of such magnetic equators varied with respect to each other and with respect to the earth's geographic equator. Of the several parameters considered, the minimum value of the total intensity of the field showed the greatest departure from the geographic equator.

In addition to these magnetic equators, the Laboratory investigated still another — one defined by minimum cosmic ray entry into the atmosphere. The cosmic ray minimum was found to be close to the line along which the noon sun is perpendicular to the earth's magnetic field at equinox. This raised the possibility that the cosmic ray equatorial minimum might shift in latitude with seasonal variations in the noon sun's position. Measurements must be made at different times of the year, however, to verify this.



The magnetic dip equator lies along points where the earth's magnetic field is parallel to its surface. The dip equator, shown here with associated lines of equal declination, is only one of several magnetic equators. The positions of these equators vary depending on the parameters used to define them, but they generally depart considerably from the geographic equator.

THE NEAR-EARTH ENVIRONMENT

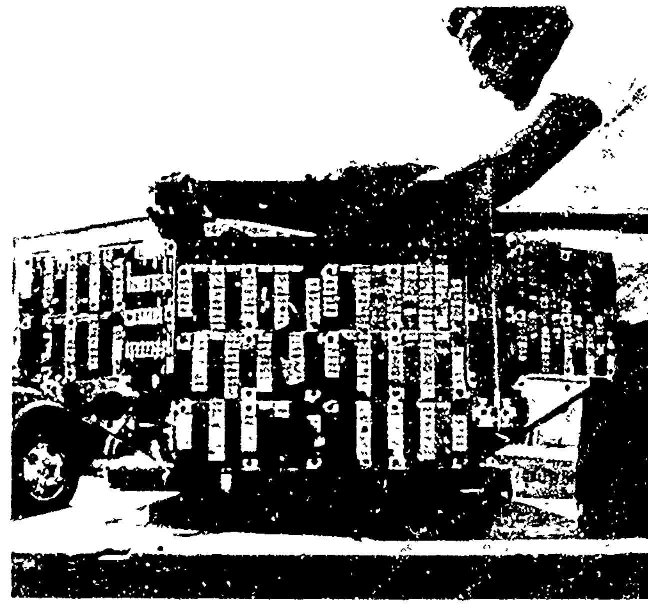
In this section, three subjects are treated. Two are discrete, unrelated subjects; the third is highly generalized and in a sense is concerned with all the research covered in the foregoing sections of this chapter, as well as with portions of the research conducted by other AFCRL Laboratories.

These subjects are the earth's radiation belts, meteoric dust particles found at altitudes in the 75-85 km region, and a newly established Laboratory Branch whose mission it is to formulate techniques for forecasting changes in the near-earth environment. To do this, the Branch relies largely on data collected under many AFCRL programs.

RADIATION BELTS: During the report period, AFCRL instrumented and launched two deep space rockets and one satellite to investigate the earth's radiation belts. The two deep space probes, flown aboard Blue Scout, Jr., rockets, were launched in a near-vertical trajectory which carried both probes to altitudes of over 15,000 km. The three-hour flights took the probes well into the radiation belts near the magnetic equator. The satellite was launched on 1 July 1963 as part of a larger launch package, and thus was given the name Hitchhiker. When the larger satellite was in orbit, the smaller AFCRL satellite separated and was injected into a separate orbit. The AFCRL Hitchhiker satellite was placed in a polar orbit with a perigee of 335 km and an apogee of about 4100 km.

From these probes, all equipped with a variety of sensors to detect the concentrations and energies of charged particles, AFCRL scientists made many refinements in the understanding of the earth's radiation belts. One refinement is the fact that it is not strictly precise to speak of two radiation belts — or of a single continuous zone. There are either two distinct belts or one continuous belt, depending on the energies and kinds of particles being measured. The AFCRL satellite found two distinct zones in which protons with energies between 1 and 5 mev were concentrated, while electrons with energies between 15 and 100 kev formed one continuous belt.

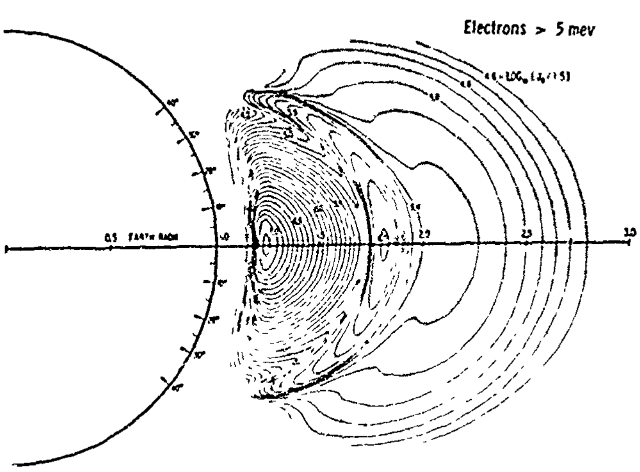
The earth's magnetic field, which traps the high-energy particles, determines the shape of the radiation belts. Thus, to describe their shape, it is useful to section this field into "L-shells," which may be considered as magnetic lines of force. The geometry of the radiation belts can then be conveniently expressed in terms of these L-shells. In this scheme, each L-shell is assigned a number corresponding to the distance in earth radii from the earth's center at which the field lines of that L-shell cross the plane of the earth's equator. Thus $L = 1$ is the L-shell which intersects the equatorial plane near the earth's surface; $L = 2$ specifies an L-shell that is about 6400 km (one earth radius) from the earth's surface at the equator, and so forth. Because the earth's magnetic field is a fair approximation of a dipole, each shell gets closer to the earth's surface as it



This AFCRL satellite gathered extensive data on the radiation belts which surround the earth. Called "Hitchhiker," it was carried aboard a larger Air Force Satellite (lower photograph) from which it separated in orbit.

approaches the poles, eventually crossing the earth's surface. Thus, the AFCRL satellite, which had an apogee of 4100 km, passed through extremely high L-shells because it was in a polar orbit. It was thus able to sample a good cross section of both the inner and outer radiation belts.

Data from the satellite showed that the single belt of 15 to 100 kev electrons was centered at L = 1.6 and extended outward to at least L = 6.9. Electrons with energies higher than 1 mev, on the other hand, formed two distinct belts centered at L = 1.6 and L = 4.5, with a sharp gap between them at L = 3.0. Protons with energies between 1 and 4 mev were found in these same two belts, but there were fewer protons than electrons in the outer belt. At all energies below 3 mev, however, there were more protons than electrons in the inner belt and in the gap between the belts, and comparable numbers of each in the outer belt.

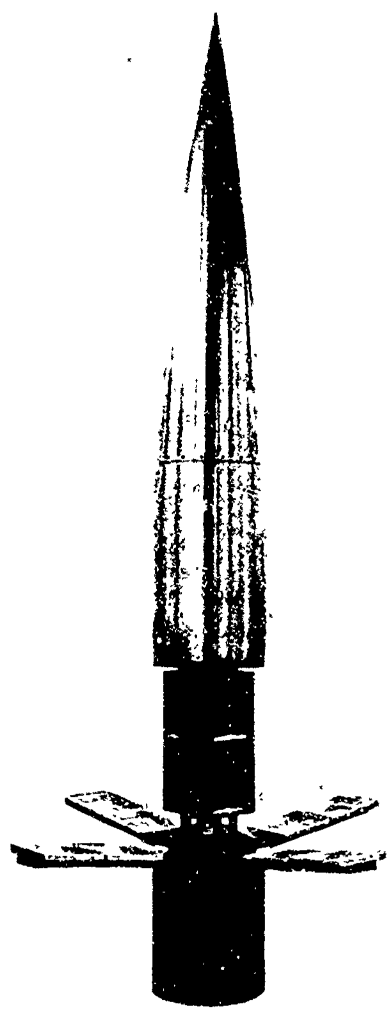


The earth's radiation belts consist of charged particles with a wide range of energies. The above chart (appearing originally in *Science*), on which each line represents electrons at a particular energy level, shows how the configuration of the belts varies with particle energy.

In the 15 to 100 kev range, the satellite detected more electrons with energies near 40 kev than at any other energy level. For example, there were about 10 times as many particles at 40 kev as at 20 kev. Forty kev electrons predominated out to L = 4 after which there was a smooth decrease in the number of electrons at a given energy level between 15 and 100 kev. These low energy electrons are not a serious hazard to man in space. But over a period of time, they could affect the performance of electronic equipment carried aboard a satellite. They are also of interest because there are so many more of them than high energy particles, and they can therefore be more readily utilized to trace long term changes in the environment.

NOCTILUCENT CLOUDS: Noctilucent clouds are luminous clouds that can be seen during the dusk and dawn periods. Most sightings of these clouds have been made in the summer months in far-north latitudes. Noctilucent clouds occur at approximately 85 km, and shine by reflecting sunlight that comes from below the observer's horizon. Until recently, no one could explain what these clouds were or how they could occur at such high altitudes.

In August 1962, AFCRL scientists, in a joint program with NASA, sent specially designed nose-cones into noctilucent clouds above Sweden, to collect samples of noctilucent cloud particles. Two successful flights were made, and some results are described in the previous report. During the present report period, Laboratory scientists completed the analysis of these experiments. The completed analysis, using electron microscope and microprobe analyzer, confirmed the preliminary results which indicated that noctilucent



"Venus Flytrap" is the designation given the rocket nose cone used by AFCRL scientists to collect micrometeorites and noctilucent cloud particles. The four collecting "petals" are shown in the open position which they assume when the rocket reaches altitude. As it falls, the petals fold back in to prevent contamination by particles in the lower atmosphere.

clouds are composed of submicron sized particles, probably of meteoritic origin. About 20 percent of these particles are coated with an ice layer.

The 1962 noctilucent cloud experiments raised several new questions about the nature of noctilucent clouds. One unexpected result was the occurrence of dark rings or halos around 20 percent of the particles on the aluminum-coated nitrocellulose collecting surfaces. In an attempt to simulate this halo effect in the laboratory, submicron particles of various materials were impacted against collecting surfaces like those in the rocket nose cones. When an aqueous slurry of submicron nickel particles was impacted, the water in the slurry turned to ice and produced halos like those found on the collecting surfaces that were flown. This led to the conclusion that the twenty percent of the particles which had such halos had been coated with ice.

Another question raised by the flights was: why do meteoritic particles collect only at certain times and in northern and southern latitudes to form noctilucent clouds, instead of being more or less uniformly distributed throughout the upper atmosphere? Flights into a cloudless sky yielded 100 to 1000 times fewer particles than flights through noctilucent clouds. The mechanism by which the ice condenses around the particles so that visible clouds are formed was also puzzling. To obtain more data that might help answer these questions, AFCRL conducted two additional series of noctilucent cloud experiments, one in the summer of 1964 and one the following summer.

Four rockets were taken to northern Sweden in July 1964 and were launched during August. Three were successfully recovered. The 1965 launches were made in July 1965 from Ft. Churchill, Canada. The particle collectors used in the 1965 series were ingeniously engineered. When the rockets reach altitude, the nose cone opens up like a flower to expose four large collecting surfaces, each about 500 square inches in area. As the nose cone falls back to earth, the petals fold back into it to prevent contamination by dust in the lower atmosphere. Recovery is by parachute. To determine particle concentration as a function of altitude, a moving shutter mechanism exposes different parts of each collector sequentially at different altitudes.

Scientists from NASA, the U. S. Geological Survey, and several other U. S. and foreign research organizations joined AFCRL scientists in this 1965 series of noctilucent cloud experiments. These flights were designed to collect not only noctilucent cloud particles, but also meteoritic dust up to altitudes of 170 km. Of the three flights made, two were failures and one was a partial success.

ENVIRONMENTAL FORECASTING: The near-space environment is constantly undergoing drastic change. No suitable techniques are presently available for forecasting these changes. Many Air Force operations and systems are, and will increasingly become, affected by near-space environmental changes. By environmental changes are meant a host of things — solar proton showers, auroral activity, geomagnetic storms, airglow emissions, ionization levels, and to some extent weather.

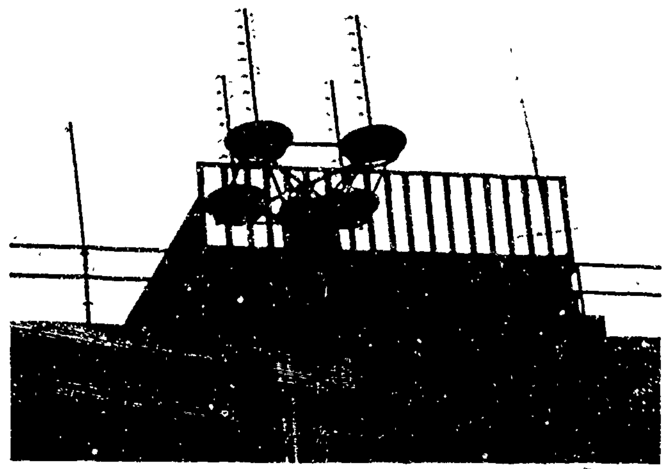
As was seen in Chapter II in the discussion of the upper atmosphere, and again earlier in this chapter on the Space Physics Laboratory, a complexity of cause and effect interrelationships are found among the many discretely investigated phenomena of the near-space and upper atmosphere environment. An understanding of these interrelationships, may provide a key to effective forecasting techniques.

In January 1964, the Space Physics Laboratory established a new Branch, the Space Forecasting Branch, whose function it is to evaluate and develop techniques for predicting changes in the near-space environment. The Branch has three subdivisions: 1) a Space Forecasting Workshop to devise methods for making predictions, 2) a data collection and decommutation facility to coordinate data from a multitude of sources and put it in a form suitable for computer processing in real-time, and 3) a publications section which puts out a bulletin of the data collected over each three-month period.

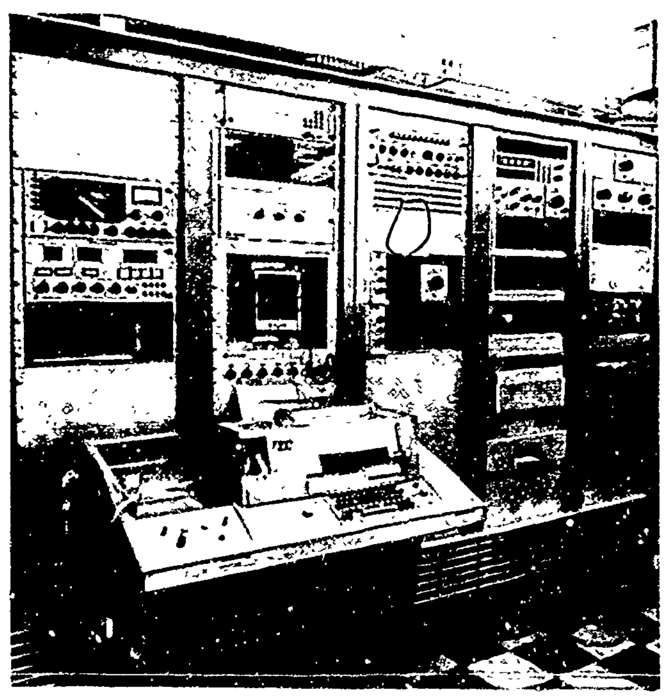
During the first year-and-a-half of the Branch's existence, the Space Forecasting Workshop concentrated on observations of solar activity. Solar activity governs all the phenomena with which space forecasting must deal — the ionosphere, the radiation belts, airglow, aurorae, and the earth's magnetic field. Initial emphasis was on solar proton shower prediction. Workshop scientists are reconstructing the life history of all solar active regions in the sunspot cycle lasting from the 1955 minimum to the present minimum. This reconstruction will show the day-to-day movement of sunspot and plage areas, variations in their size and magnetic fields, the frequency of occurrence of different types of flares, and the affect they had on the near-earth environment. When they have completed such a reconstruction, the scientists can then develop a climatology of solar active regions and establish probabilities for specific types of solar flare occurrence. At the very least this will allow a comparison between past and future behavior of active regions. Flare data will be in a form to which statistical regression procedures can be applied for analyzing similar data in the future. No laboratory heretofore has undertaken so thorough a collection and analysis of solar data.

To support the Space Forecasting Workshop in such studies, a variety of data processing equipment was installed in the spring of 1965 for the Data Collection and Decommutation Facility. This Facility has the responsibility for converting data into a form suitable for computer processing. For space forecasting, data must be rapidly processed before it becomes outdated by changing conditions in space. With this new equipment, scientists can make much better use of AFCRL's widespread and varied environmental sensors. These sensors include probes carried aboard scores of balloons, rockets and satellites and the large telescopes at Sagamore Hill Radio Observatory and Sac Peak Solar Observatory.

To speed up data collection from satellites, a quad-helix antenna was installed on the roof of an AFCRL building at Hanscom Field for direct collection of telemetered data from satellites. Also installed was a data transmission link between the Sacramento Peak Observatory and Hanscom Field. The link is a VIDEX unit over which photographs of the sun taken at Sunspot, New Mexico, can be transmitted to the facility in a matter of minutes. For more routine data collection needs, a commercial teletype has been leased.



A quad-helix antenna, mounted atop an AFCRL building at L. G. Hanscom Field, Bedford, Mass., makes possible direct reception of satellite data for immediate use in forecasting conditions in space.



Data from a wide variety of space environmental sensors can be processed in real time at this data decommutation center for rapid utilization by AFCRL's Space Forecasting Branch.

ENERGETICS RESEARCH

Energetics is the study of chemical, electrical, thermal, and solar energy sources and the processes whereby energy is converted from one form to another. The goal of AFCRL's research in energetics is not primarily device development, but rather to gain a clearer understanding of the mechanisms controlling the operation and efficiency of energy conversion systems. An understanding of these mechanisms is the essential precursor to better power sources for Air Force missions, particularly those in space.

Energetics research crosses the disciplinary lines of physics, chemistry, and biology. The research has four distinct parts: 1) *electrochemistry:* research on batteries and fuel cells, 2) *thermal processes:* analysis of efficiencies of thermionic converters, 3) *quantum processes:* the study of photoconducting and semiconducting materials for converting solar energy to electrical energy, and 4) *photobiological systems:* the study of the capture and storage of solar energy by plants.

ELECTROCHEMISTRY: The electrochemistry program is concentrated on material transport and charge transfer in the vicinity of electrode surfaces, novel electrodes for fuel cells, the inhibition of catalyst poisoning, and reforming processes for making hydrocarbon fuels usable in fuel cells. Related efforts deal with reaction kinetics at electrode surfaces and with adsorption phenomena as a function of surface character. Other areas of research are treated in greater detail in the following subsections.

THERMAL PROCESSES: In a thermionic converter, a current is generated by heating the emitter electrode until it becomes so hot that electrons are "boiled off" its surface. Most vacuum tubes make use of this principle. To increase the efficiency and lifetime of a thermionic converter, the converter may be filled with a metallic vapor such as that of cesium. However, the electrodes of cesium-vapor converters adsorb some of the cesium during operation. As deposits build up, the electrode surfaces become distorted, adversely affecting converter performance.

To study the problem, Laboratory scientists designed a high precision electron beam probe to measure the electron work function of electrode metals. (Electron work function is defined as the energy needed to dislodge a free electron from its surface and is the measure of efficiency of a thermionic emitter.) With this high precision probe, AFCRL will study the electron work function of different metals and their rates of cesium adsorption.

In addition, studies of the transport properties of thermally ionized cesium plasmas are being planned. This work will proceed in three steps. Initially, the electron densities and the frequency of collisions between electrons and atoms in a cesium plasma in thermal equilibrium will be determined as functions of cesium gas pressure and temperature. Results will be compared with predicted electron densities for cesium at the observed temperatures and pressures. This will serve as a check on the accuracy of the measurement techniques and the applicability of generally accepted theory. Similar experiments will be made using several mixtures of a noble gas and cesium.

The second step will consist of the same measurements, but thermionic electrodes will be placed in the gas to determine what effects their metal surfaces will have on the plasma. In the third step, a potential difference will be established between the electrodes so that a small current flows through the plasma. The effect of this current on electron densities and collision frequencies will then be studied.

PHOTOBIOLOGICAL PROCESS: Photobiology is the study of how plant substances use light as a source of energy for their life-sustaining chemical reactions. Research in photobiology can lead to improved ways of converting the sun's energy to electric power — for example, through the regeneration of fuel cells by solar energy. During the report period, the Laboratory explored the several steps of energy conversion during photosynthesis. This research involves photochemical reactions in chloroplast that has been isolated from green plants, the different forms of chlorophyll, and electrochemical properties of chlorophyll.

In the first area, a new method was developed to measure the rate and types of photochemical reactions in the chloroplast. It is based on the amperometric reduction of ferricyanide at a rotating platinum electrode. In the second area, the Laboratory succeeded in separating the two forms of chlorophyll — chlorophyll a and chlorophyll b — by organic solvent-water extraction and ion-exchange chromatography. From this work they also obtained chlorophyll aggregates which absorb light in a new long wavelength range. Electrochemical properties of chlorophyll were studied by polarographic and photovoltaic methods. It was found that chlorophyll b is reduced at lower voltages than chlorophyll a, and that hydroquinone, a chemical used in developing photographs, reduces chlorophyll in the presence of light by a photovoltaic effect.

The responses to light of other substances besides chlorophyll were also studied. These substances included sulfhydryls (compounds having the formula RSH, where R is an organic radical containing only carbon and hydrogen), disulfide (S_2) groups, and collagen, a structural protein polymerized by light. During the period, Laboratory scientists found a relationship between sulfhydryl groups, fluorescence and energy transfer. Using this relationship, they explained the photovoltaic effect that occurs when light induces an electron transfer from sulfhydryl groups to conjugated molecules in an excited state. Changes in the shape of organic molecules after irradiation with light were also studied. Collagen was found to exhibit a fluorescence that depended strongly on the shape of the molecule. When irradiated, it lost the ability to form fibers. This research is being extended to study the structural protein responsible for light-induced changes in the shape of chloroplasts.

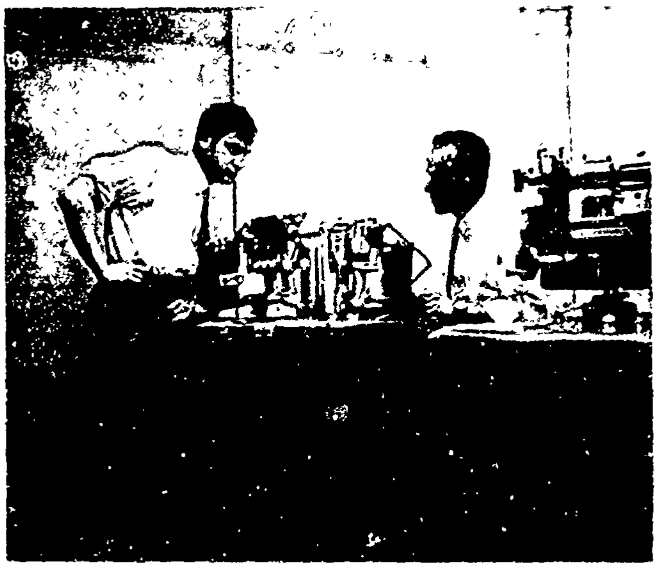
QUANTUM PROCESSES: The solar cell, presently the most widely used energy-converter in space vehicles, is the best example of a quantum process device. The Laboratory's research in quantum processes, such as photoconduction and semiconduction, is devoted to the search for new and better materials to convert solar and other electromagnetic energy into electricity. Emphasis is placed on organic substances whose conductivity greatly increases when exposed to light, and on understanding the mechanism by which various substances convert light into electricity. The Laboratory's research in quantum processes has developed along three separate but closely related lines.

The first of these is a synthesis program in which materials having novel and relatively efficient photoconductive and semi-conductive properties are synthesized and analyzed by standard spectroscopic techniques — infrared, UV and visible spectrophotometry, electron spin resonance and nuclear magnetic resonance. Various techniques are employed for the purification of these new materials. Among the methods used are vapor-phase chromatography, recrystallization, zone melting and sublimation.

A new series of photoconductive complexing agents was prepared from the nitro-substituted 9-dicyanomethylene fluorene system. Interest in photoconduction processes in heteroaromatic molecules containing noncarbon atoms such as nitrogen, oxygen, and sulfur, led to the preparation and purification of phenazine derivatives, bis-benzoxazole derivatives, and extended conjugated hydrazones. Some very large organic molecules were also studied. These substances included the reaction product of hexachlorocyclopentadiene with malononitrile. This reaction product is a strongly paramagnetic, semiconductive, water-soluble polymer. Research on metal complexes included preparation of selected aluminum and lithium phthalocyanine derivatives. The reaction of dilithium phthalocyanine with iodine yielded a charge transfer complex, the first such complex to be isolated in the pure state from the phthalocyanine molecule. It has a specific resistivity of about 10^4 ohm-cm.

The second segment of this work is a screening program in which the electrical properties of the new materials are characterized by their photoconduction efficiency as a function of temperature and the wavelength of the illuminating radiation. Continued improvement in the design of the equipment for this work led to development of a system which automatically plots conductivity as a function of temperature, thus permitting rapid reproducible analyses. Ratios of photoconductivity to dark conductivity higher than 50,000 have been observed with this instrument for several of the materials synthesized.

The third part of the program consists of crystal-structure analysis. Representative materials, in single-crystal form, are analyzed by x-ray diffraction to elucidate the internal molecular geometry as well as the orientation of the molecules relative to one another. The theoretical program is concerned with evaluating the influence of steric arrangement on parameters such as the resistivity and mobility of electronic materials.



AFCRL scientists study novel compounds to determine the relationship of their molecular and crystal structure to their physical and chemical properties.

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V Terrestrial Sciences Laboratory

The program of the Terrestrial Sciences Laboratory falls within four discrete disciplinary areas: geodesy, gravity, geology and seismology. The Laboratory is concerned with the precise measurement of distances between land masses, with gross terrain features, their stucture and mineralogical properties, with the mass of the earth and the distribution of this mass, and with the structure of the earth and propagation of seismic waves through it.

As in the case of the other environmental sciences, satellites have provided a significant new tool for this research. During the reporting period, increasing use was made of satellites and larger roles given to satellites in future planning. Following is a brief summary of the work carried out during the 24-month period of this report:

Laboratory geodesists were concerned with three basic programs, all involving satellites. First was the continued acquisition, reduction and analysis of data from the ANNA 1B geodetic satellite. This unique geodetic vehicle was launched on 31 October 1962. As of 30 June 1965, the satellite's flashing lights were still operating, and data were still being collected. The second program involves passive satellites, which include the Echo satellites, but primarily involve special passive geodetic satellites carrying reflectors into orbit from which ground-based laser pulses are reflected. In both the active and passive cases, the object is to photograph the light from a satellite by two or more separated cameras so that, by triangulation, distances between points on the earth can be computed. The third geodetic program is concerned with the geodesy of the moon. Still in the preliminary study stages is the instrumentation for lunar satellites to be used for determining the size, shape and gravity of the moon.

Lunar geodesy or selonodesy — the measurement of distances between points on the moon — is a relatively new Laboratory program. It involves the careful analysis of photographic plates from observations all over the world.

Laboratory gravimetrists are attempting to refine gravity values over much of the earth's surface. They are also working on methods for predicting gravity anomalies. Much of the work relating to prediction requires detailed statistical and correlation studies. Because measured gravity values exist over only a small portion of the earth, estimates of gravity in unsurveyed areas are made primarily by interpolation. The almost nonexistent state of gravity measurements at altitude has created the need that these requirements be satisfied by extrapolation of surface values. Last, and of major importance, is work on airborne gravimetric instrumentation which has the objective of obtaining worldwide measurements of gravity values.

Laboratory geologists have concentrated on a worldwide study of natural terrain which might be suitable for aircraft landing and spacecraft recovery areas. The work includes both the determination of the geologic nature of these areas, and the development of instruments for airborne terrain surveys. One of the most interesting new geological instruments developed during the period was a "multiband" spectral camera capable of photographing the earth at nine selected wavelengths in the visible and near infrared spectrum. The multiband camera provides a new interpretative technique for photogeologists. When used on satellites, the camera might provide useful data for both terrain analysis and the acquisition of "multiband" spectral photographs of other planets.

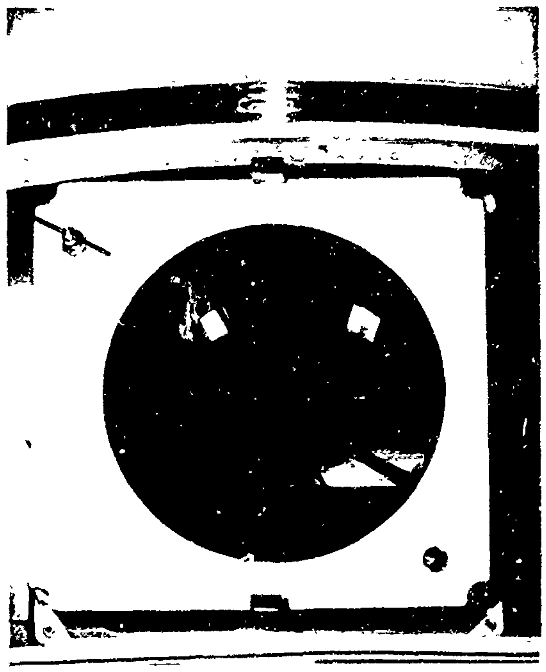
Laboratory seismologists, using a large shear press, have conducted experiments in the Laboratory on materials of the type making up the earth's lower crust and upper mantle. The behavior of these materials under varying conditions of temperature and pressure is of special interest because it provides laboratory evidence to confirm existing theories, or form the basis for new theories on the mechanism involved in coupling seismic energy from underground explosions to the surrounding medium. This is one of several studies being conducted at AFCRL which are designed to give greater insight into the source differences between natural and man-made seismic events and thereby lead to methods for differentiating between seismic waves from earthquake sources and those from underground nuclear tests. The AFCRL seismology program is part of Project VELA UNIFORM which is sponsored by the Advanced Research Projects Agency.

GEODESY

Apart from the relatively coarse requirements of the cartographer, the size, shape and mass distribution of the earth has historically been a matter of purely scientific interest. Satellites and missiles have changed this. Geodetic parameters are factors in the precise launch, orbiting and reentry of space vehicles, and in the establishment of precise trajectories for ballistic missiles.

A few years ago, geodesists were optimistic that only a few uniquely designed geodetic satellites would be necessary to achieve some ultimate refinement in geodetic data. This vision has now faded somewhat. While satellites still occupy a central position in geodetic research, geodesists are now resigned to long term data collection and refinement involving a diversity of satellites and satellite experiments. The earlier view was one which did not fully account for atmospheric influences — turbulences, refraction — which bend and distort optical signals from the satellite, and which make the accuracy of any single measurement uncertain. Thus the problem becomes a statistical one in which accuracy is related to the number of observations.

PROJECT ANNA: The ANNA-1B satellite, which as of 30 June 1965 had completed more than two and one-half years of active useful life, is probably the most significant new geodetic research tool of the past century. Jointly planned and developed by the Army, Navy, NASA, and AFCRL, ANNA originally transmitted both optical and radio signals. The AFCRL optical beacons (flashing lights) and the Navy radio doppler transmitter have far exceeded their specified lifetimes of six months. An Army transponder to measure distance failed after one month. The optical signal is used as a target by widely spaced cameras for three-dimensional triangulation.



To obtain short-interval photographic images of passive satellites such as ECHO and the forthcoming PAGEOS, AFCRL developed this chopping shutter which is soon to be used with operational camera units. With these cameras, passive satellites are photographed against a background of stars. By triangulation, geodetic measurements are made.

The relative positions of the flash images with respect to the stars provide angular data. This information is used to establish the relative positions of the various camera stations. Apart from phototriangulation, continuing observation of the satellite's behavior in its roughly circular 600-mile orbit also aids in understanding more about the earth's size, shape and mass, since these influence the orbits of aerospace vehicles. As of 30 June 1965, the Aeronautical Chart and Information Center (data collectors for USAF on Project ANNA) had nearly 1,000 camera plates with verified images taken by Air Photographic and Charting Service (APCS) ANNA observing teams. This number does not include observations of other cooperating groups.

ANNA has had an interesting lifetime in that for a six-months period (January-July 1963) the strobe lights operated at a greatly reduced intensity — then returned spontaneously to full brilliance. Shortly after the ANNA light system corrected its own malfunction, it was deemed necessary to use the AFCRL alternate over-ride transmitter to activate the lights. This limited the use of the satellite only to periods when it was within line-of-sight of the transmitter at Bedford, Mass. This proved to be a small limitation, however, as the satellite dutifully responded and flashed its lights as far away as 1,845 miles from the transmitter. During the period from September 1963 to January 1964, an intensive series of observations were made using a network of ten USAF precision cameras located in the southern U. S. In these tests, the ANNA beacons were successfully photorecorded simultaneously by three or more cameras on 60 different occasions. The data thus obtained were used to develop relative positions of the observing stations (separated by 700-1200 km) to an accuracy better than 1:100,000.

After the completion of these tests, AFCRL transferred the alternate transmitter (and thus the control of ANNA) to the APCS camera group at Orlando, Florida, where it is still successfully operating.

It is encouraging to note that a new National Geodetic Satellite Program has been started. Using the successful work of Project ANNA as a jumping-off point, the new NASA-DoD-Department of Commerce program includes the design, development, launch and observation of a series of geodetic satellites. These range from active satellites which will carry an assortment of radio transponders (doppler, Secor, range-range rate), flashing lights, reflectors, and supporting equipment to passive reflecting spheres.

The next satellite launch under this program will be the fully instrumented GEOS (Geodetic Explorer) during the fall of 1965. AFCRL will participate in the program with continuing Laboratory field tests of laser, camera and other geodetic satellite techniques.

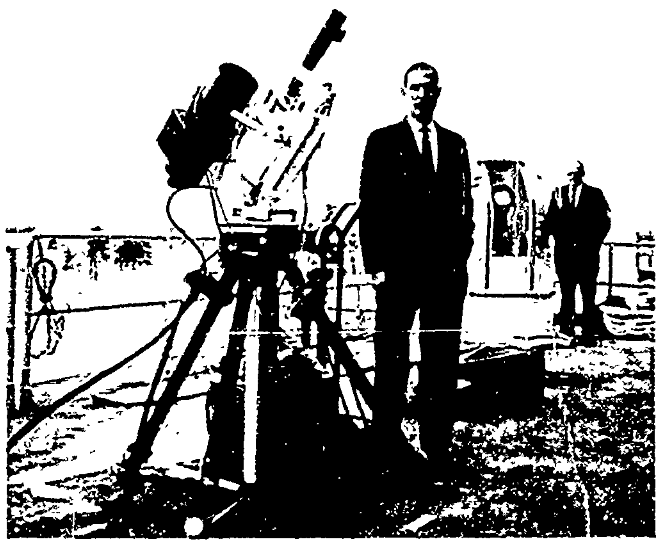
PASSIVE GEODETIC SATELLITES: Most planning with respect to future geodetic satellites is focused on passive configurations. Advantages are obvious — extremely long lifetimes, simplicity and economy. Two approaches to the use of passive geodetic satellites are under consideration at AFCRL.

First, shutters have been developed for AFCRL long focal-length cameras which permit photographic chopping of traces of continuously illuminated satellites (such as ECHO in sunlight). Simultaneous observations by several cameras so adapted can be handled much the same way as ANNA flashes to produce relative positions of the observing sites.

A second method of using passive satellites in geodesy consists of flashing a light from the ground to a reflective satellite and photorecording the reflection from the satellite. In this approach, lasers located at several geodetically significant sites beam light pulses activated by a common triggering circuit to the satellite. Prismatic reflectors on the satellite reflect the signal back to the vicinity of its source where the light is photographed against the star background, as in the ANNA technique. These reflectors do not require specially designed satellites but can ride on many satellites of opportunity.

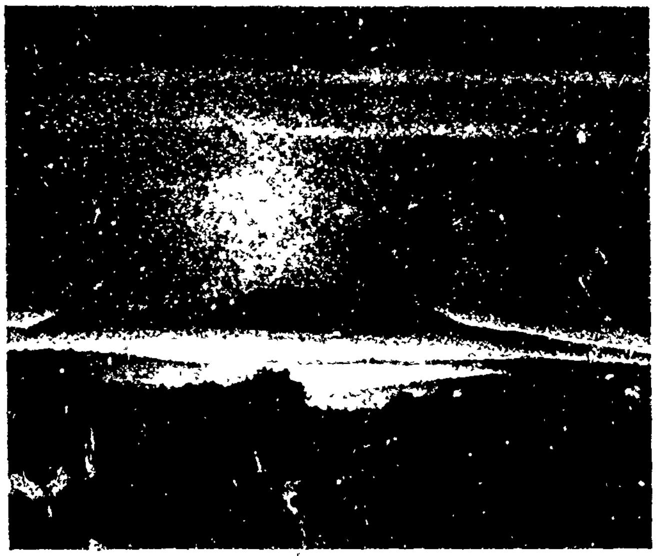
The Laboratory began to make laser beam propagation tests in the latter part of 1963. These tests had a variety of purposes — the study of aiming capabilities of various laser cavity mounts, of relative merits of various types of laser transmitters, and of cavity cooling methods. For example, a 300-joule pulsed ruby laser was used in tests of its beam over a path between Bedford, Mass., and Mt. Wachusett, near Fitchburg, Mass., a 66-mile round trip. Because of low elevation angle, the beam had to travel through a much denser segment of the atmosphere over this nearly ground-level path than would be the case in an earth-to-satellite path. Even with the considerable atmospheric attenuation, the reflected beam was seen and photographically recorded easily and repeatedly.

The first chance to test a passive satellite geodetic system occurred in October 1964, when NASA launched its Beacon-Explorer B. This satellite carried, as one experiment, several banks of prismatic reflectors so arranged as to point toward earth. Early attempts at hitting the satellite with a pulsed laser beam and capturing the reflection on a photographic plate pointed out the imperative need for very accurate aiming and timing of the laser system. However, on 21 January 1965, AFCRL scientists were successful in this type of test and they have since repeated it.



This laser gun and associated power supply (foreground) and PC-1000 camera system (background) located atop and AFCRL building at Hanscom Field, Mass., are used to transmit and record laser signals reflected from satellites. AFCRL performed this feat for the first time in January 1965.

MATHEMATICS AND COMPUTATION: More than simple calculations in geometry are involved in deriving distances between two points on the earth by use of geodetic satellites. Therefore, much AFCRL effort has gone into developing computational methods for extracting maximum information content from geodetic satellite data. The satellite-ground position data were looked at from three mathematical perspectives.



Barely discernable at the top of Mt. Wachusett, 33 miles west of AFCRL, is a point of light which is the reflection of a laser light transmitted from AFCRL and photographed by the PC-1000 camera.

These were orbital constraints, intervisible position determinations, and long-line azimuth determinations.

Investigation into the use of orbital constraints and data from an active geodetic satellite has resulted in a computer program called DOC II. This program performs a differential correction to the orbital elements and/or station positions from weighted observations of range, range rate, azimuth-elevation and/or right ascension-declination of close earth satellites.

Investigation of the intervisible (viewing of the satellite at two or more sites) method of station position determination has resulted in a computer program that takes intervisible observations of range, direction cosines, camera plate coordinates, and computes the locations of the observing stations. All observing stations need not observe the same light flashes. The use of a minimum number of observations of the satellite ANNA has resulted in station position determinations with positional accuracies, relative to the North American 1927 Datum of 1:90,000 to 1:260,000.

A method for determining the geodetic azimuths of lines ranging from 300 km to 1400 km has been formulated. This method requires simultaneous optical observations of a flashing satellite-borne light by two or more sites. ANNA observations provide the basis for the formulations. By this method azimuths with an accuracy of better than one second of arc have been recorded.

LUNAR AND PLANETARY GEODESY: The AFCRL program in extraterrestrial geodesy — determining the size, shape and gravity fields of the moon and planets — was concentrated during the report period almost exclusively on two aspects of lunar geodesy. The first relates to lunar cartography — mapping. The second concerns instrumentation for measuring earth-moon distances. Geodetic techniques developed with respect to the moon lend themselves in some instances to adaptation for planetary geodetic studies.

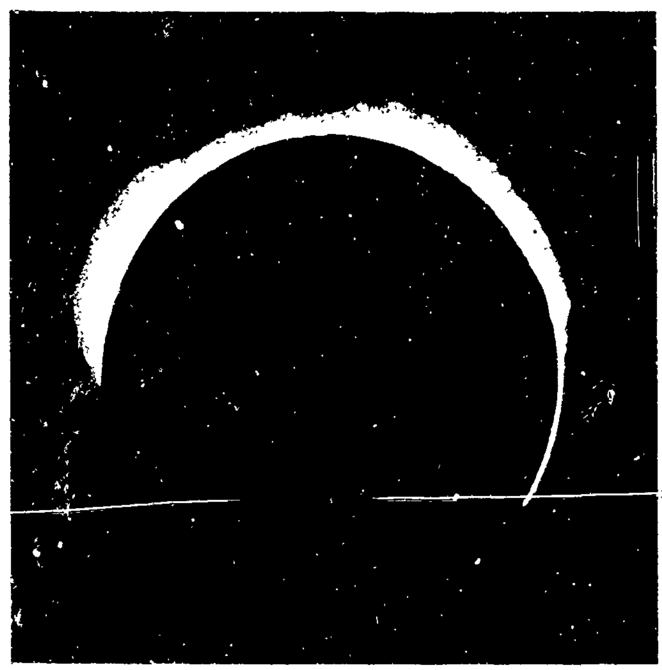
Constructing an accurate map of the moon would seem a rather simple job. After all, a good high resolution photograph of the moon could be used like a map. But from the standpoint of the lunar geodesist (selenodesist) the photographic "map" is not very good. It does not provide a reliable basis for measuring distance between two points on the surface of the moon, even though with our best telescopes, features on the visible lunar face can be photographed with a resolution of about one-half mile.

There are several reasons for this. Distortions are introduced onto the photographic record by atmospheric turbulence and refraction. Two photographs of the moon taken with the same telescope where "seeing" conditions change may show differences in distances of several miles from one reference point on the moon to another. It is also due to the poor geometry of the problem. The moon at mean lunar distance of 384,400 km subtends an angle of only about one-half a degree.

Using lunar photographs acquired from medium-aperture, long-focus terrestrial telescopes, the selenodesist must make measurements with a linear comparator instrument to high precisions. Such precisions are required since the photographs are taken from the earth and any error in measurement is increased about 221 times at the moon. An error of only one arc second translates to an error of about two km on the moon.

Another limiting factor is that terrestrial telescopes do not operate at their diffraction limits due primarily to the degrading effect of the earth's atmosphere. This constrains photographic resolutions.

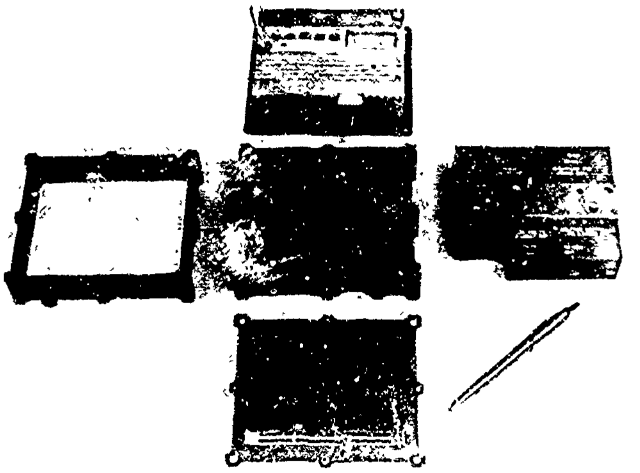
Greater accuracy can be obtained through statistics. Involved, as a first step, is the examination of numerous lunar photographic plates — some more than 60 years old — available from observatories all over the world. Glass plates rather than film are used wherever possible because glass is more rigid. A statistical approach is taken for the reduction of data using maximum likelihood theory in which various error-inducing factors are considered. This theory is being tested with sets of measured observations acquired from selected lunar photographs. The complexity of factors involved in the approach encourages the use of large-storage computers for the reduction and analysis of data.



Irregularities along the limb of the moon are enhanced when illuminated by the sun during a solar eclipse. This photograph was taken during the eclipse of 20 July 1963 in Maine.

One of the limitations of precision lunar cartography is that the exact distance from the earth to the moon along all points of the lunar orbit is unknown. To refine existing figures on earth-moon distances, AFCRL has developed a prototype lunar transponder that will permit electronic ranging between the moon and earth.

The transponder (which receives and retransmits radio signals) is designed



This small, simple lightweight transponder developed for placement on the moon can transmit radio signals to the earth. From these radio transmissions, more accurate selenodetic measurements can be made.

for placement on the visible face of the moon. It is designed to withstand shock of 3000 G's in any direction for a duration of three milliseconds. It weighs a mere 4.3 pounds, excluding batteries, and has a volume of about 90 cubic inches. Similar to a frequency modulation transceiver, the transponder receives a frequency-modulated 5052 Mcps carrier signal and simultaneously retransmits the signal on the same antenna on a 5000 Mcps carrier. The transponder was designed to meet general lunar hard landing requirements. Such a device could also be used as a navigational beacon. If sufficient observational data are acquired from such a lunar transponder, knowledge pertaining to the lunar orbit, the solar parallax, and the moon's librations could be independently confirmed, tested and extended. AFCRL has recommended to NASA that the small transponder be carried aboard an early pre-Apollo moon flight.

GRAVITY

The AFCRL gravity research program is not concerned with the basic physics of gravity — that is, with the nature of gravitational radiation, the verification of the quantized nature of gravity, or the study of gravity as one of the four fundamental forces of the universe. AFCRL is interested in gravity measurements and in the design of more sensitive and versatile instruments for measuring gravity at the surface of the earth and in the gravity field (the external gravity) that surrounds the earth. It is interested in establishing worldwide calibration standards. Last, it is interested in techniques which will permit interpolation (prediction) between surface gravity values, extrapolation of the surface gravity field to elevated points, and the reduction of aerial gravity measurements to required mean surface values.

THE EXTERNAL GRAVITY FIELD: Studies of the earth's gravity and gravitational field are essentially an extension of studies in geodesy. If the earth were a smooth sphere of homogeneous or regular composition, gravity calculations would be relatively easy. Given a few data points, it would be simple to calculate gravity fields with great precision. But the earth is not a smooth sphere, and its mass is not evenly distributed.

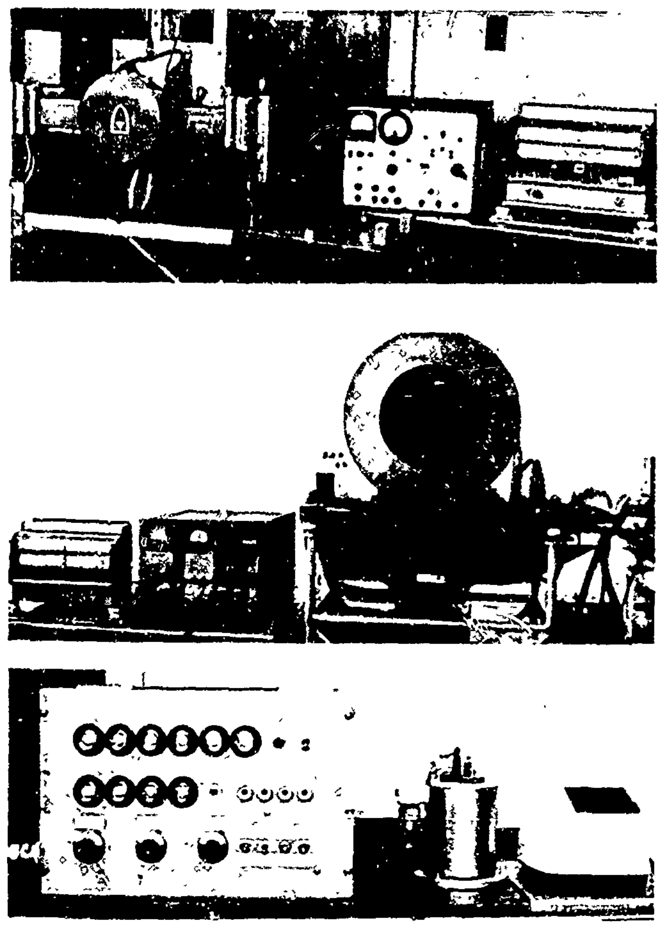
The external gravitational field of the earth refers to the gravitational attraction of the earth at various distances from its surface. This attraction varies with the mass distribution of the earth. Because the mass distribution is irregular, the gravitational field varies in a manner not easily predictable.

AFCRL hopes to develop techniques

for deriving information on gravity values all over the earth and at all altitudes based on limited measurements. Several methods are being investigated for doing this. The problems concerning the "upward" continuation of gravity values to high altitudes from the anomalous field observed at the surface have been solved and various methods, including computer programs for handling a large number of points, have been tested and results published. Theoretical solutions for the "downward" continuation problem are also available. This means that measurements made with AFCRL's airborne gravimeters, can lead to the computation of surface mean values from gravity profiles observed at various altitudes. Correlation studies and statistical methods have been conceived and tested for estimation of gravity anomalies in unobserved or inaccessible areas.

WORLDWIDE GRAVITY SURVEYS: Worldwide gravity surveys have lagged because of the lack of international standards. This need led AFCRL to initiate the Worldwide Gravity Standardization Program. This program is being carried out with the cooperation of the International Association of Geodesy. At a meeting held in Paris in September 1962, agreement was reached on the establishment of a single worldwide gravity system. (AFCRL's C-130 gravity measurement aircraft, flown to Paris for the meeting, was a well-received conference sidelight.)

At the Paris meeting agreement was reached on the establishment of three interrelated parts of an Absolute World Gravity System: 1) an accurate world calibration standard, 2) a first-order world gravity net, and 3) an international absolute reference system.



Three airborne gravimeters used by AFCRL are (top to bottom) the LaCoste-Romberg gravimeter, the Askania-Graf gravimeter, and a quartz miniature digital airborne gravity meter.

The starting points of the worldwide gravity system are three north-south calibration lines, along each of which are eight or nine standardization stations. These are the American calibration line extending from Point Barrow, Alaska, to South America, the Euro-African calibration line extending from Norway to South Africa, and the West Pacific calibration line extending from Fairbanks, Alaska, to New Zealand.

Many international agencies are cooperating in the overall project. Of the three calibration lines, the Euro-African calibration line and the American calibration line were completed in December 1964. By "completed" is meant that gravity values based on common standards have been established at all stations along each line. Observations along the West Pacific calibration line will start in the spring of 1965. The three calibration lines and ultimately the connecting network between these lines will result in a world gravimeter standard and a first-order reference network.

GRAVITY INSTRUMENTATION: The historic lag in the establishment of worldwide gravity standards resulted in part from inadequate gravity instrumentation. Only in recent years have instruments of high precision been developed. AFCRL's foremost contributions to gravity research have been in airborne instrumentation. AFCRL airborne equipments have steadily improved since AFCRL performed the first successful airborne tests in 1958.

During the reporting period, AFCRL's airborne gravity instrumentation was modified and improved. The original electronics of both the La Coste-Romberg and Askania-Graf airborne gravity meters have been transistorized. A newly designed stabilized platform with a high precision vertical reference unit has been acquired and tested. The AFCRL C-130 and KC-135 aircraft have been completely instrumented with doppler navigation systems, astro-trackers, radar altimeters, and aerial cameras. Digital converters and memory storage of the converted data have been designed and fabricated, and mating with the airborne systems for flight testing is in progress.

In addition, AFCRL has concentrated on two basic types of gravity instrumentation. These are gravity meters and the pendulum apparatus. The conventional gravity meter, in principle, consists simply of a weight and a spring. With gravity meters, the relative differences in gravitational acceleration at two or more sites can be measured very accurately, provided the instruments are well calibrated. The pendulum apparatus is based on the principle that the period of a pendulum of a given length will vary with the acceleration of gravity at a given location. Pendulums can be used for both absolute and relative measurements of gravity. If both the length and period of the pendulum are determined in an experiment the result will be absolute. If only the period is observed at two or more sites and the length is assumed to remain constant, the results will be relative gravity differences between the observation stations.

Both types are used by AFCRL in its work on the world gravity net. Both have advantages and disadvantages. Gravity meters are more sensitive than pendulums, but pendulums at present permit the observer to more accurately establish relative values between two sites having large gravity differences. The establishment of gravity standards requires use of both relative and absolute equipment. For our work on the world calibration standard first-order gravity net, we have supported pendulum measurements to establish relative values between reference points and gravimeters for obtaining more sensitive readings at intermediate stations.

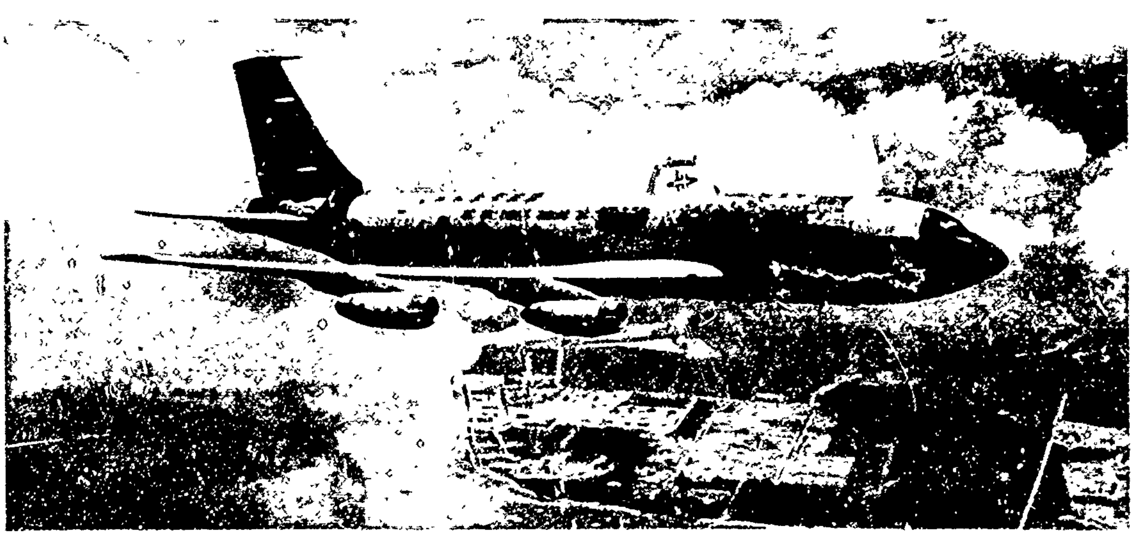
AFCRL's relative and absolute pendulums have undergone extensive testing and evaluation during the reporting period. Ultra-high vacuum techniques have made possible the swinging of these pendulums for many days with only a very small decrement. Although many relative pendulum problems have been solved and operating characteristics are viewed as good, additional refinements and field testing are planned. The absolute apparatus is operating well and observations have been made for determining repeatability and correlation with amplitude. Individual pendulums have been modified so that their direct and reverse periods agree to better than 10^{-7} seconds.

In addition to the absolute pendulum apparatus, AFCRL is investigating two new techniques for absolute gravity measurements. One is a portable apparatus using a free-falling interferometer mirror as the dropped object and a gas laser for a visible light source. The second technique is one involving the gravitational acceleration of charged particles. A feasibility study of the latter technique was completed and construction had begun at the close of the report period.

GEOLOGY

United States commitments in the underdeveloped parts of the world have resulted in a new operational role for the Air Force which, when judged against the massive, technological sophistication of other Air Force operations, has an anachronistic flavor. In this new role, natural terrain features weigh heavily in military planning. It is within this context that AFCRL has undertaken a worldwide study of the more flat-lying of these landforms to point out the existence of natural aircraft landing areas. In addition, these areas are being considered for recovery operations in future spacecraft programs.

There are many natural landing areas all over the world from which Air Force strategic, tactical and logistical aircraft might operate. These provide effective, secure, and relatively inexpensive operational bases permitting



This KC-135 aircraft equipped with airborne gravimeters was used extensively during the period for making test survey measurements.

Some of the equipments in the Laboratory's KC-135 aircraft used for making gravity surveys are shown. The equipments include power control panels, level-bubble controls, and accelerometer controls.

the aircraft to disperse and to maintain emergency landing capabilities. Whether aircraft can use natural terrain depends on two interacting factors. These are aircraft design — wheel loading, tire pressure and landing gear configuration — and terrain characteristics, such as strength, moisture content, roughness, and mechanisms of soil failure or displacement.

AFCRL scientists are seeking to define the relationship of these factors in order to predict the deformation behavior of the soils of natural terrain, subsequent geological development of the landforms and their surface materials, and the suitability of various photographic and other electromagnetic sensors in airborne surveys of natural terrain. AFCRL scientists have estimated that there are hundreds of flat land surfaces, previously thought to be unusable or inaccessible, capable of supporting fully loaded heavy aircraft.

A second aspect of the Laboratory's geology program is one which looks ahead to satellite surveys of the terrain features of Mars, Mercury and other terrestrial planets. The initial approach is indirect, involving the study of data accumulated by earth orbiting satellites. Comparisons of earth satellite data with the known geological features of the earth, will assist in the interpretation of data from similar sensors designed to study the geological features of other terrestrial planets.

DRY LAKE BEDS: Of all the natural areas on earth capable of supporting aircraft, playas (dry lake beds) are perhaps the most useable. These lake beds are flat surfaces composed primarily of hard, dry clay and silt. They are found in considerable number in arid regions throughout the world, and are typical of the western United States. The low rainfall in these regions permits the use of many playas throughout the year. When they are not completely dry or when they are salt-encrusted, however, no vehicular traffic of any kind may be possible. Even the extremely dry playas may contain desiccation crack patterns which may hinder operations.

For the past several years, AFCRL has investigated a large number of playas in the U. S. with respect to size, local geology, soil strength, seasonal conditions, and surface and subsurface properties. Soil samples were obtained to depths of 20 feet and analyzed for mineralogical and mechanical properties. Depth to water table was determined by electrical resistivity techniques, and subsurface stratification was investigated by seismic, magnetic and gravimetric exploration. Continued determination of moisture content at selected sites was correlated with ambient and long-term climatic records to establish a forecasting procedure of soil strength reaction to rainfall conditions. Instrumentation was developed to enable continuous monitoring of soil moisture and strength conditions at remote sites. Such remote monitoring will speed the development of procedures for forecasting the usability of a site.

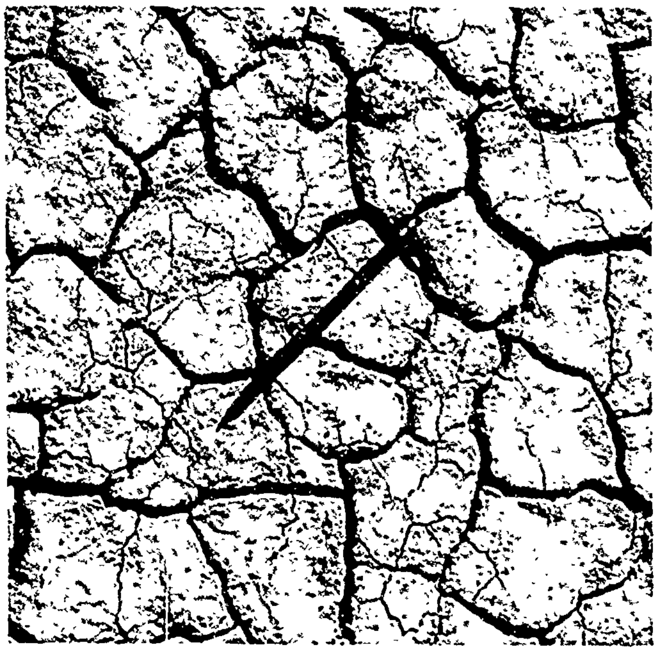
Loading tests of playa surfaces were conducted to simulate the static and dynamic forces of various aircraft, and tentative use criteria were established. These were then verified by actual takeoff and landing tests of several operational aircraft on selected dry lake beds.

A portable refraction seismograph is used to measure discontinuities beneath desert basins. The record provides clues to the weight bearing properties of the soil.

LANDFORM ANALYSIS AND PROPERTIES OF MATERIALS: Research is continuing on the origin, evolution, and mineral composition of landforms. Detailed field studies are being made of the thickness of sedimentation, chronology of morphology, and drainage and fracture patterns of basin regions of the western United States. Hopefully, this will enable prediction of their life cycles. An expansion of this effort was marked by the establishment of a new mineralogical section within the Laboratory. X-ray diffraction, differential thermal analysis, petrographic, spectrophotometric, and other analytical techniques and instruments are being employed to define the structure, composition, and physical properties of terrain materials.

This typical dry lake bed, of the type widely scattered in the western U. S., shows superficial effects of vehicle and aircraft traffic.

A related study was concerned with "quick" clays, which cause sudden landslides. Crystal structure of clay minerals was investigated and the cause of instability was found to be leaching of the sodium ion from unstable crystals. The addition of electrolytes to the clay



Development of small and large fissures is a function of soil composition. The top photograph shows familiar mud tracks of the type that develop when fine-grain soil dries. Cracks interact to form polygonals a few inches across. In the lower photograph, giant contraction fissures on the dry lake bed at Edwards AFB are shown. Polygonal patterns 200 feet across have been formed. These large open fissures preclude aircraft or automobile travel.

material decreased the instability under static loads and dynamic forces. Similar investigations are considering the importance of clay chemistry in landslide areas at Anchorage, Alaska, Palos Verdes, California, and Ogden, Utah.

Research is being conducted on the mechanics of transient dynamic loading and subsequent surface deformation of terrain. Mathematical models of deformation of assumed elastic, plastic, and visco-elastic materials are being developed, and refinement of theories of shear failure was begun by treating granular material systems as macromeritic liquids instead of "ideal" solids. Load tests on well-defined systems of materials are being accomplished to define stresses, strains, and deformation parameters and to apply these to prediction of surface deformation. Power spectrum analyses of theoretical and empirical surface roughness models will be made to determine their effect on the loading conditions.

Tropical soil patterns have been investigated to determine if their appearance on aerial photographs can properly be correlated with actual mineralogic and physical characteristics. In an effort to correlate the development of U. S. playas with other desert regions of the world, a landform study of African desert basins was undertaken during the reporting period.

TERRAIN ALTERATION: Natural terrain otherwise suitable for aircraft operations may still be marginal because of low weight bearing properties. Methods for quick and effective stabilization of these soil areas with a minimum of effort are required. One promising technique utilizes foamed explosives which can be spread on the surface like a blanket. When detonated by a small blasting cap, the explosion both compacts the soft soil and drives the moisture downward, resulting in increased strength in the top layers. Foaming and detonating capabilities of the product were experimentally verified and small-scale field tests were conducted. Such a technique may also be applied for melting and disintegration of hard snow or slushy ice enabling the preparation of landing strips on arctic terrain.

AIRBORNE SENSING: Surveying and cataloguing potential landing areas in remote parts of the world could be done more quickly and economically if suitable airborne techniques and instrumentation could be developed. Airborne surveys, of course, enable rapid coverage of large areas which may be inaccessible from the standpoint of geographical isolation or political denial.

A program to establish multisensor capability for airborne determination of geological and environmental data has been in progress for several years. Experiments and tests under controlled conditions are being conducted to verify the feasibility and operating sensitivity of many sensors throughout the electromagnetic spectrum. Because the Army, with respect to vehicle traffic, has a related interest in the weight-bearing soil characteristics of terrain in remote areas, the Army Corps of Engineers has joined AFCRL in some of this work. Among the remote sensing equipment and techniques under study are a four-band radar system, a pulsed VHF radio wave propagation technique, various infrared sensors, passive microwave techniques, and gamma-ray spectrometry. These are applied to soils of known structure, composition, density and moisture content. A "catalogue" of terrain identification parameters is thus being built up. Use of the instrumentation in an AFCRL C-130 aircraft is planned. This will permit experimental testing and calibration of the sensors under operating conditions.

A unique camera system has been developed which photographs the earth's surface in nine separate regions of the visible and near-infrared spectrum. Changes in vegetation, soil properties, and seasonal effects can be detected by interpretation of the relative brightness and tonal difference appearing on this "multiband" imagery. Such information can be much more readily extracted from this type of imagery than from conventional black-and-white or color photography. The camera employs three rolls of aerial film, each traversing three matched lenses equipped with appropriate filters to give a narrow spectral band input to the film. The earth surface properties appear strikingly different in terms of the reflectance in the various energy bands.

GEOLOGY OF OTHER PLANETS: As an extension of airborne sensing, the Laboratory has initiated a program for the detection, interpretation, and analysis of geologic conditions of the earth and other terrestrial planets from extremely high altitude sensor imagery. The correlation of general terrain patterns of geologic significance with spectral reflectance imagery from photographic and other sensors is being investigated. Photography from X-15 and U-2 aircraft flights, rockets, and satellites will enable delineation of gross features of the earth. Patterns of imagery of other planets could then be interpreted in light of similar patterns of known geological features of the earth.

Joint participation in research programs of NASA was initiated with emphasis on the use of multiband photography (discussed above) for interpretation of terrestrial conditions. An in-house photointerpretation facility has been established to process and interpret photographic source materials.

SEISMOLOGY

When an event is recorded at a seismological observatory, the seismologist would like to know whether the event was natural or man-made. The research in seismology at AFCRL is directly concerned with the detection of underground nuclear explosions. The program is being conducted for the Defense Department's Project VELA-UNIFORM. It is designed to evolve techniques for distinguishing between natural and man-made events. The first step calls for broadening the knowledge of seismic phenomena.

Seismological research at AFCRL can be grouped under one of several headings: seismic source identification techniques, hypocenter determination, worldwide seismicity, seismic propagation phenomena, and seismic detection methods.

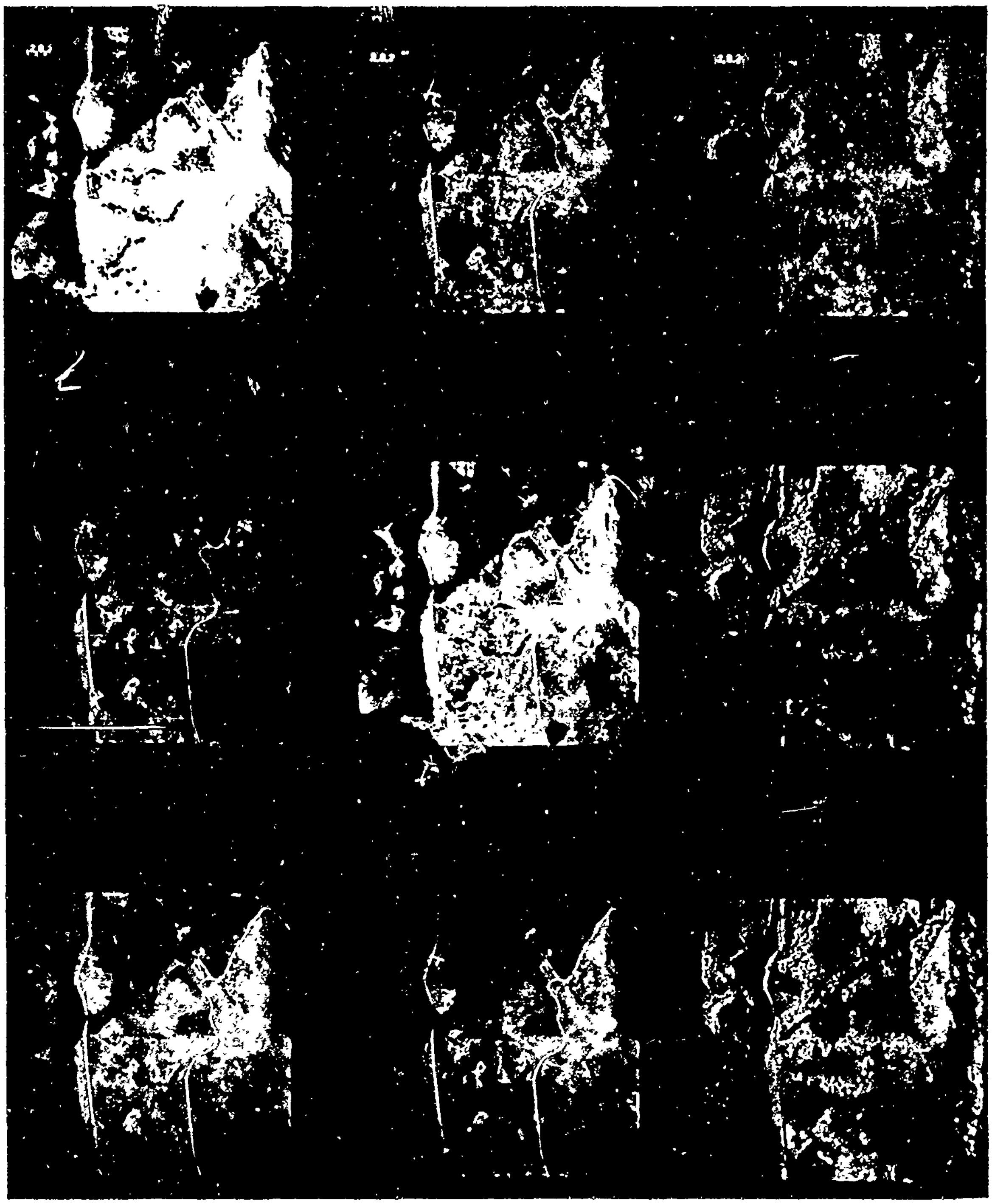
SOURCE IDENTIFICATION: To develop source identification techniques which can be used to discriminate between earthquakes and underground explosions, a study has been initiated to define a set of statistical parameters which are not directly related to knowledge of source function, but which do have distribution functions that show separation for time-function ensembles for earthquakes and explosions. After the ensembles are assembled, parameters which appear to indicate ensemble differences are computed and plotted to indicate like and unlike ensemble characteristics.

Some of the parameters being considered are: 1) cross-correlation between the initial P-wave and later arriving energy to determine the presence of crustal reverberations, 2) distributions of mean square differences between normalized auto-correlations of ensemble members, 3) frequency distributions of normalized auto-correlation functions, energy ratio of deconvolved signals (signals where inverse filtering techniques have been used to remove the effect of crustal layering beneath the recording station), 4) coherence within an ensemble and between different ensembles to obtain a distribution function relating predictability within and across ensemble members, and 5) higher order cross-correlation functions.

In addition, records from both earthquakes and explosions are being analyzed in order that statistics may be compiled on various identification techniques which are based on known or theoretical difference in source mechanics. Some of these identification techniques are direction of the first motion of the initial P-wave, ratio of the first motion to second motion deflection, depth of focus determinations by using $_pP$-P time interval, the so-called "lonesome" P, prevailing period of surface waves, and the ratio of the peak amplitude of surface waves to P waves.

Another study under source identification is concerned with the use of the radiation patterns of surface waves to determine the type of source, thereby serving as a possible diagnostic criterion.

Laboratory scientists have developed a theory for the radiation pattern of Rayleigh waves from a number of sources which approximate real earth-



A wide range of tonal variations between the differing points of the visible and infrared spectrum are shown in this series of photographs taken with the nine-lens multiband camera.

The multiband camera takes simultaneous photographs of terrestrial surfaces in nine different narrow regions of the visible and near-infrared spectrum.

quake and explosion sources. Sources considered were a single force, a force dipole without torque, a single couple, a double couple without torque (all of arbitrary orientation), and a spherically symmetrical compressional source. Using layered matrices, the source coefficients have been derived for a medium consisting of a number of parallel homogeneous layers. For an asymmetrical source, such as a faulting source, the theory predicts that an asymmetrical surface wave radiation pattern should be produced, and that an explosion source should produce a symmetrical pattern.

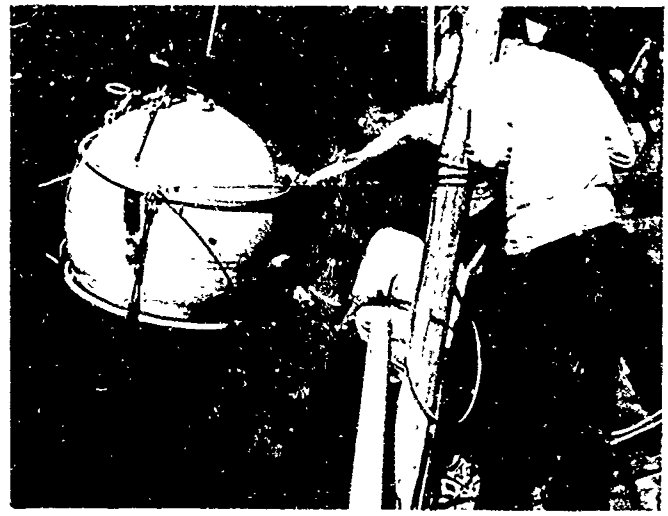
As a test of the theory, an AFCRL contractor digitally analyzed a number of seismograms from both earthquakes and explosions. After performing Fourier analysis and phase equalization at various azimuths, the following conclusions were drawn: 1) the radiation patterns of Rayleigh waves from underground nuclear explosions in tuff and alluvium indicate that the source mechanism is an explosive force acting as a step function in time, 2) the collapse of the cavity, which follows many of the large explosions in alluvium and tuff, generates Rayleigh waves with reversed polarity relative to the explosion, 3) an explosion in granite produced a surface wave radiation pattern with nearly perfect double-couple symmetry in both phase and amplitude (this type of pattern is expected from earthquakes, not explosions, and must have resulted from either cracking or the release of strain in nearby faults), and 4) the amplitude and initial phase spectrum of Rayleigh waves are more complex for earthquakes than for explosions.

HYPOCENTER DETERMINATION: Essential to a test detection network is the ability to determine with accuracy the location and depth of seismic disturbances. If this can be accomplished, a large number of events can be eliminated from consideration as possible nuclear events because of location and/or depth of occurrence. However, local and regional variations in travel times of seismic waves and the failure of conventional methods for determining depths where the source is shallow have made this task difficult.

Under AFCRL sponsorship, a number of studies have been initiated to determine crustal structure and/or regional travel times. Regions included in these studies are New England, the southeastern U. S., the central U. S., northwestern U. S., northwestern Canada, the Alpine region of Europe, and northern Europe. The most comprehensive of these studies has taken the records from 126 North American stations for eleven earthquakes occurring in the Pacific. After determining the epicentral location as accurately as possible with computer techniques, residuals to the standard travel time curves were computed for each of the stations. The residual is assumed to be a composite of a station correction, an error in the standard (Jeffreys-Bullen) travel time curves, and a baseline correction caused by inhomogeneities in the distribution of stations. The results show a group of large positive residuals (corresponding to late arrivals) in the region of Nevada and Utah, and a group of large negative residuals (early arrivals) extending from Lake Michigan to Arkansas. Events from other azimuths are now being considered to determine the azimuthal effect on station corrections and travel time residuals.

The use of computer programs has increased the accuracy with which epicenters can be located. For example, a plot of previously determined epicenters for earthquakes occurring near mid-oceanic ridges shows them falling within a belt 200 to 500 miles wide. However, a plot of the recomputed epicenters, using computer techniques, finds the epicenters occurring within 50 km of the ridge crests, providing much information on the geological structure and the existence of fracture zones.

Locating hypocenters for events originating near island arcs such as the Aleutian Islands, poses a special difficulty. The special nature of the problem led to a joint AFCRL-Air Force Technical Applications Center-U. S. Coast and Geodetic Survey experiment in the Aleutian Islands area during August and September 1964. The U. S. Coast and Geodetic Survey established land stations on the islands of Atka, Ulak, Tanaga, Semisopochinoi, and Amchitka, with AFTAC occupying a site on Adak. AFCRL placed five



The AFCRL ocean-bottom seismometer is prepared for launching off the California coast. This seismometer can remain on the ocean floor for periods up to 30 days. A number of tests were also made off the coast of the Aleutian Islands, in the Gulf of Mexico, and near the Hawaiian Islands during the reporting period.

ocean bottom seismographs (see seismic detection methods below), along a line south of the Aleutian chain extending from Atka to Amchitka. To calibrate the network of stations, a series of underwater high explosive charges were detonated through the network. With the travel time information provided by the charges, hypocenter coordinates of earthquakes occurring within the network could be accurately determined, thereby permitting the calibration of travel times to stations outside of the network.

WORLDWIDE SEISMICITY: Of particular concern to a nuclear test detection system is the number and location of earthquakes occurring each year with equivalent magnitudes of nuclear events. Previous studies of worldwide seismicity, such as that performed by Gutenberg and Richter in 1954, have

This is the interior of the central station of the AFCRL network of seismometer stations (contractor operated) in New England, to which seismic data from outlying sites are transmitted automatically. In the background, are recording and processing equipments.

used data from earthquakes with computed magnitudes of 6.0 or greater. Since most nuclear events have magnitudes less than 6.0, a study was undertaken to compile statistics on the frequency of occurrence, energy release, and location of earthquakes which occurred during the years 1960 and 1963.

Analysis of the 1960 data has been completed and the results compiled in an AFCRL publication. Because station perceptibility and station coverage in 1960 were limited, only the data for events of magnitude 5.0 and greater are considered complete. With well over 4000 events recorded in 1960, the breakdown shows 1428 earthquakes of magnitude 5.0 to 6.0, 234 of magnitude 6.0 to 7.0, 22 of 7.0 to 8.0, and one of magnitude 8.5. The total seismic energy released by earthquakes of magnitude 5.0 and greater during 1960 is approximately 5.6×10^{24} ergs, with 4.6×10^{24} ergs of this total being released in southern Chile.

In addition to the worldwide seismicity study, a number of local studies are underway also. These studies center around AFCRL's New England network. Composed of stations at Milo, Machias, and Caribou, Maine, and one at Berlin, New Hampshire, the network automatically telemeters the seismic data from the stations to a central recording station at Weston, Massachusetts. Each station is equipped with a three-component Benioff short-period seismometer with a built-in calibration circuit which can be pulsed from Weston. The seismometer translates ground motion into an analog voltage which is fed through an amplifier to a voltage controlled oscillator. The resulting FM signals from the three components are multiplexed and transmitted over leased telephone lines to Weston where they are recorded on magnetic tape. Playback through a bank of discriminators returns the signal to its original analog voltage form for processing.

SEISMIC WAVE PROPAGATION: Much of the information on the nature of the source of seismic energy is lost during propagation of the signal from the source to a distant seismic station. Some of this loss is due to the filtering effect of the propagating medium; part is due to distortion of the signal which results from crustal reverberations and local noise.

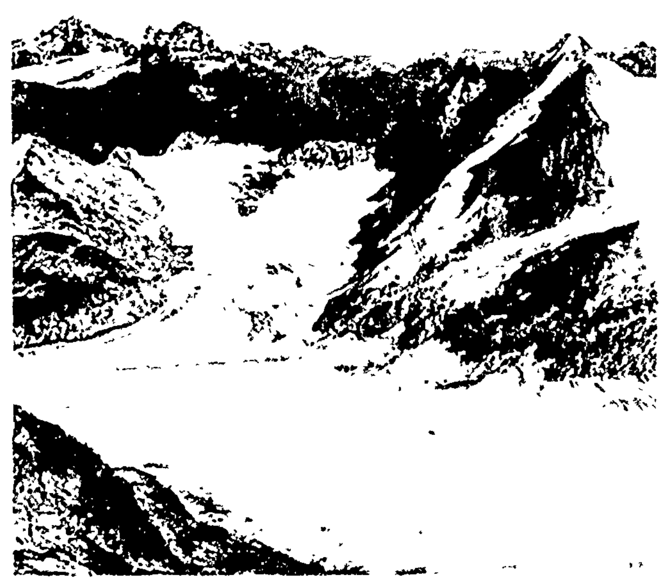
To broaden the knowledge of wave propagation phenomena and to develop new diagnostic criteria for determining type and possible depth of the source, a large number of theoretical studies have been undertaken. Limited space precludes discussion of these many studies. Nevertheless, they should be itemized to show the scope and depth of the AFCRL research devoted to seismic wave propagation.

The research includes: signal-to-noise ratio and spectra of explosion-generated Rayleigh waves in a dissipative half-space; the effect of source depth on Rayleigh wave spectra in a layered earth; long-time response predicted by exact elastic ray theory; high frequency elastic wave theory; development of a program for computing theoretical seismograms for a multilayered media; reflection and transmission of plane compressional waves; the use of PS converted seismic waves as a means of identifying underground explosions; the use of surface wave rejection filters to record mantle waves of low order; relative excitation of long and short period waves by earthquakes and explosions; calculation of the theoretical response of a homogeneous spherical earth to a point source of unit step time dependence; propagation of compressional, torsional, and mixed pulse of unit step form in flat layered solids; propagation of unit step pulses in realistic models of the earth; model study of the effect of depth on the first pulse of a seismic wave; propagation of seismic waves in the presence of discontinuities; model studies of explosion generated waves and the development of visco-elastic wave propagation theory.

SEISMIC DETECTION METHODS: One method which has shown much promise for increasing the ability to detect small magnitude events in the presence of high background noise is the use of seismometers in deep boreholes. In some instances, improvements in signal-to-noise ratio of ten-fold have been achieved by placing instruments in boreholes at depths as great as 10,000 feet.

Because seismic background noise is apparently a function of geological environment as well as being a function of depth, AFCRL is investigating the ambient noise at various levels in deep holes in an attempt to identify the mode of propagation of the noise and to relate it to the physical environment. It has been assumed that the noise consists of Rayleigh waves propagating in a horizontally stratified earth.

To date, measurements have been made in three deep wells, located at Hempstead and Juno, Texas, and Williston Basin, North Dakota. For all measurements in the well, corresponding measurements are made with compatible equipment at the surface and at 500 feet for comparison purposes. Deep well observations are made at 1000 feet intervals. Preliminary analysis of the data suggests that a considerable fraction of the noise at 1 cps consists of



Seismic activity in the Alps was investigated for the Laboratory under contract. The Alps are of interest because they are a young mountain formation and a rich variety of seismic activity is associated with them.

incident P waves. Further analysis is necessary to confirm this as well as other postulations on the nature and variation of noise with depth as a function of geological structure.

To evaluate the possibility of using the deep ocean as a location for detection instrumentation, AFCRL is developing and testing ocean bottom seismographs. After initially demonstrating the feasibility of making seismic observations at depths as great as 20,000 feet, AFCRL has directed the development and testing of an operational unit which is capable of recording for a 30-day period at depths to 25,000 feet. The unit's highly sensitive seismometers can measure earth displacements of the ocean floor as small as 0.1 millimicrons. It has a solid state amplifier system that records at three levels of amplification — 2,000, 20,000, and 200,000. Its slow speed (0.0075 in/sec) tape recorder is capable of recording 30-day's data on an 8-inch reel of tape. Most important, it has a sonar recall system which permits the unit to be brought to the surface on command, and a radio beacon for location and recovery. Operational tests of the unit were conducted in the Aleutian Islands area during August and September of 1964, producing the first extended period of records made on the ocean floor.

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VI Optical Physics Laboratory

AFCRL's research in optical physics can be divided into three broad areas: 1) atmospheric optics, the study of the scattering of optical radiation by the atmosphere, 2) infrared radiation studies which involve the determination of the infrared absorption spectra of atmospheric constituents such as ozone, carbon dioxide and water vapor, and the emission spectra of infrared radiation sources such as natural and nuclear-induced airglow, and 3) the physics of high intensity light sources — lasers and arc-lights. Since a great deal of this work concerns the behavior of optical radiation in the aerospace environment, many of the results have a direct bearing on the Air Force's operational capabilities, as well as being of significant scientific value.

As a scientific discipline, physical optics differs from classical optics in that it is concerned with the fundamental nature of interactions between optical radiation and matter rather than such things as the geometry of image formation. The wavelengths which lie within the province of optical physics range from 10 angstroms where the ultraviolet and X-ray portions of the electromagnetic spectrum merge, to 1 millimeter (10 million angstroms) where the far infrared blends into the microwave radio frequency spectrum. Although only a small fraction of this broad range of wavelengths is occupied by visible light, the devices used to measure radiation throughout it are similar to those used in the study of visible radiation. These devices include spectrometers, interferometers, photometers, and radiometers, all suitably modified to measure a particular segment of the spectrum.

Since optical physics is both an environmental and a laboratory science, AFCRL's research in this area requires the instrumentation of aircraft, balloons, rockets, and satellites as well as extensive experimental and theoretical work in the Laboratory. During the two year reporting period considerable progress in the study of atmospheric optics was made with the development of new optical payloads to be carried aloft by balloons and rockets to measure the spectral and intensity distribution of scattered sunlight in the upper atmosphere. Improvements in modeling the atmosphere's optical properties were also made. The resolution of infrared spectrometers was improved, resulting in a much greater refinement in measurements of absorption and emission spectra. Programs aimed at determining the infrared "signatures" of a variety of launch and reentry vehicles were continued. Also continued, based on 1962 nuclear test data, were studies to determine the effects of nuclear-weapon-induced optical radiation on defense systems. Optical experiments to be performed in space by Project Gemini astronauts were developed.

The first measurement of the infrared emission spectra of the chemical reactions which produce natural airglow was made. The Laboratory's progress in laser physics consisted of a thorough experimental study of confocal ruby lasers, and a significant contribution to the mode theory of laser operation. All of this research contributes to a more fundamental knowledge of the processes which govern the interactions of radiation and matter. This knowledge is prerequisite to the design of future Air Force surveillance, reconnaissance, and detection systems.

Scores of original Rayleigh manuscripts have been acquired by the AFCRL Library, giving AFCRL the finest archival collection of Rayleigh papers in the world. This collection, made to obtain the fourth Lord Rayleigh's airglow observations, also contains many other important scientific papers of the Lords Rayleigh, including the original of the third Lord Rayleigh's paper on Argon, for which he won the Nobel Prize.

ATMOSPHERIC OPTICS

AFCRL's research in atmospheric optics is primarily concerned with the determination of how various factors, such as aerosol content, altitude, and solar angle, affect the distribution of optical radiation in the atmosphere. One goal of this work is to provide the Air Force with the capability of predicting this condition under a wide variety of operational circumstances. Visibility, which is directly related to the optical condition of the atmosphere, is an important factor in many Air Force operations such as photographic reconnaissance, target location and identification, and detection and tracking involving optical sensors. In addition to this goal, AFCRL's research in atmospheric optics is directed toward gaining a more fundamental understanding of the processes that govern the interaction between optical radiation and the atmosphere.

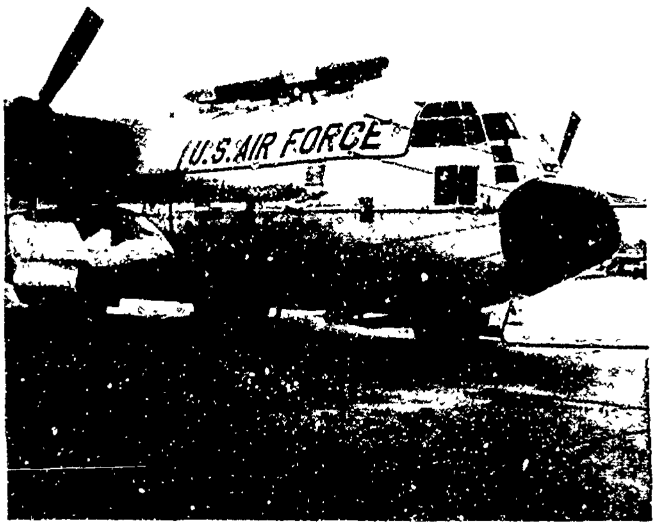
AIRCRAFT, BALLOON, AND ROCKET MEASUREMENTS: Most research in atmospheric optics must be, by its very nature, observational rather than theoretical. That is, the optical condition of the atmosphere can be determined only by direct measurements. To make such measurements, the Laboratory uses a highly instrumented C-130 flying laboratory, balloons and rockets. The most basic instrument used in all these vehicles is a spectroradiometer, suitably modified for the particular vehicle and investigation. It can measure the intensity distribution of skylight and earthlight across the near ultraviolet, visible, and near infrared spectrum of 2000 to 9000 angstroms. From these measurements, realistic "optical models" of the atmosphere can be developed, and theoretical studies can be guided by experimental evidence.

One of the primary steps toward developing an optical model of the atmosphere, and therefore one which must precede any detailed discussion of the measuring techniques involved, is that of determining to what extent the distribution of light in the atmosphere depends on scattering by aerosols, and to what extent on scattering by atmospheric molecules.

Aerosol scattering is a form of Mie scattering, which includes all scattering by particles whose diameters are the same order of magnitude as the wavelength of light. Mie scattering does not depend on wavelength as much as does molecular, or Rayleigh, scattering in which the particles (molecules) are several orders of magnitude smaller than the wavelengths of the light they scatter. Atmospheric molecules scatter some blue wavelengths to a greater extent than longer wavelengths; aerosols scatter light less selectively, producing a characteristic white haze when present in high concentrations. Since the concentration of aerosols varies a great deal with location and meteorological conditions, while the molecular content of the atmosphere is fairly homogenous at a given altitude, aerosol scattering is much more difficult to predict than molecular scattering.

The light which is scattered comes from two sources. There is direct sunlight which, when scattered, becomes "skylight," and there is sunlight reflected from the earth, or "earthlight." Thus measurements of the spectral and intensity distribution of light from airborne sensors must include both hemispheres — the upper and the lower. The distribution of both earthlight and skylight are necessary for a complete description of the atmosphere's optical properties. The instrumentation requirements for measuring the two are somewhat different, however, because earthlight has a lower intensity and different spectral distribution from skylight. The C-130 carries instrumentation for measuring both. For balloon measurements separate payloads for measuring earthlight and skylight have been developed. (This came about because the instrumentation for measuring earthlight was developed first, rather than from any intrinsic necessity for separate payloads.) This aircraft and balloon-borne instrumentation, and also that planned for installation in a rocket nose cone, are described in detail in the following paragraphs.

The C-130 carries several instruments for collecting aerosols and measuring ambient temperature, pressure, and humidity, as well as photometers and spectrometers for measuring earthlight and skylight. With this combination of instruments AFCRL scientists can correlate the meteorological condition of the atmosphere with its optical properties. Also included among the C-130 instrumentation are ion probes and a microwave refractometer. The microwave refractometer is used to measure the atmosphere's index of refraction at microwave frequencies in studies designed to correlate increases in sky brightness with increases in the microwave refractive index.



This highly instrumented C-130 aircraft is used by the Laboratory to measure the distribution of scattered light in the atmosphere. Below, the project director makes observations through the C-130's periscope during a flight.

AFCRL's balloon-borne instrumentation for measuring earthlight consists of 27 different photometers mounted so that they always point downward. Each photometer has about a three degree sight angle and most of the units use a cadmium sulfide cell to detect the radiation. The spectral range covered by the whole photometer array is from 3900 angstroms to 9100 angstroms. Each photometer has a filter centered on a different wavelength at 200 angstrom intervals. (Bandpass of each is 75 angstroms. Also included in the array are cameras for taking high-speed infrared and color photographs of the terrain below. In this way, the features of the reflecting surface can be identified. All data are recorded by an onboard, seven-channel magnetic tape recording system. The recovered tape is played back and displayed on a recording oscillograph for analysis.

Balloon measurement of skylight, particularly in the spectral region between 2000 and 4000 angstroms, has required the development of special instrumentation because of the extreme variation in the intensity of scattered light in this region. A spectrometer is coupled to a solar biaxial pointer. The spectrometer is mounted in such a way that it scans in a vertical plane from the horizon up to the point where the balloon obscures the sky above it. The solar biaxial pointer works in such a way as to keep the sun in this vertical scanning plane at all times, so that the intensity of skylight as a function of the angle between the sun and a particular portion of the sky can be determined.

A major problem of measuring sky radiation is that of plotting its intensity distribution across the spectral range. During this reporting period the principal mechanical and optical elements for doing this were designed and fabricated, but the electronic circuitry for signal processing is still in the testing stage. To date, two cylindrical containers each housing six photometers, have been built. Each of the six photometers has a different spectral range. The two containers are to be mounted on opposite sides of a platform which is magnetically stabilized. The measuring units are to be programmed for a step-by-step spiral scan of the upper hemisphere.

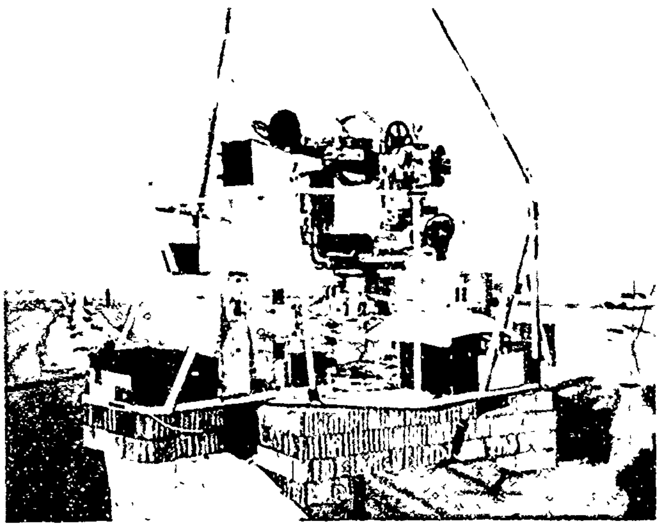
AFCRL scientists working on the aircraft and balloon programs hope to establish measurements on a routine basis, although trouble with the vehicles has so far prevented this. In spite of this difficulty, some useful measurements were made during this reporting period.

Little is known about scattering at altitudes above 100,000 ft., where heavily instrumented balloons cannot reach. To help fill the need for optical studies of the region, AFCRL has extended its field program to include the development of a rocket-borne photometer for obtaining data on the scattering of optical radiation at extreme altitudes. The photometer is equipped with detector sets for seven different spectral ranges. The photometer assembly is designed to fit into the nose cone of a Nike-Cajun rocket. When the rocket reaches the altitude where measurements are to be made, the top of the nose cone will be ejected and the photometer detectors exposed to the skylight radiation. During the flight up to this altitude, the photometer will be continually calibrated by means of a diffuse light source located in the tip of the nose cone. At this reporting, the photometer assembly has successfully passed its preflight testing and is being readied for delivery to the rocket integration team. Launching will occur sometime in the summer of 1965.

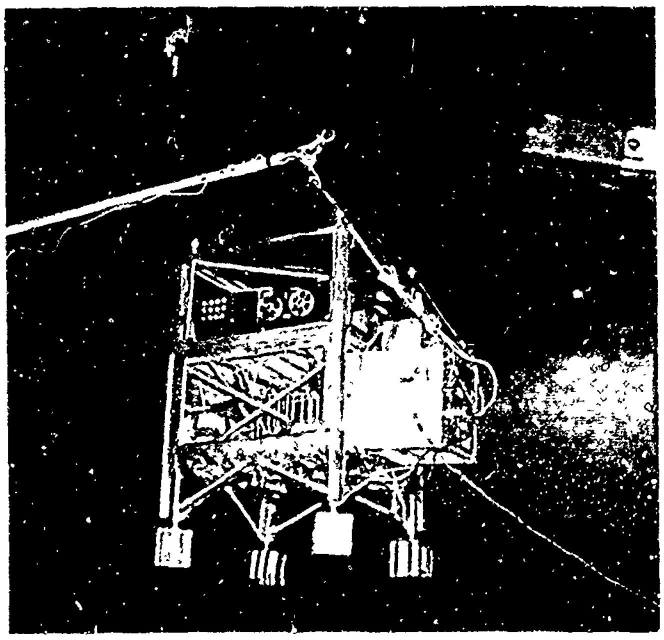
SEARCHLIGHT MEASUREMENT OF AEROSOLS: During the period July 1963 through June 1965, the Laboratory also continued its investigation of aerosol scattering in the atmosphere using the two techniques of searchlight probing and observation of the solar aureole. The former technique is used to study the backscattering effects of atmospheric aerosols and the latter is used for study of forward scattering.

For the aerosol backscattering study, a narrow-beam searchlight was set up at a location in White Sands, New Mexico. The scanning and recording device was located at the Sacramento Peak Observatory so that there would be a large baseline (30 km) between the searchlight beam and the direction in which the scanner was pointed.

The searchlight beam was pointed upward at a constant angle, and the light collector scanned up and down along the beam, recording the intensity



This balloon payload is used to measure the distribution of ultraviolet sunlight in the upper atmosphere. The mounting atop the platform supports an ultraviolet spectrometer (the horn-like device) which is coupled to a solar pointing device.



Measurement of earthlight was done with this balloon payload. The cluster of cylinders in the center of the framework is an array of downward-looking photometers.

of the light scattered from it at each point. The data were reduced and plotted. The theoretical molecular scattering was then calculated and plotted on the same graph as the total observed backscattering. The difference between the total observed scattering and the molecular scattering represented the scattering due only to aerosols.

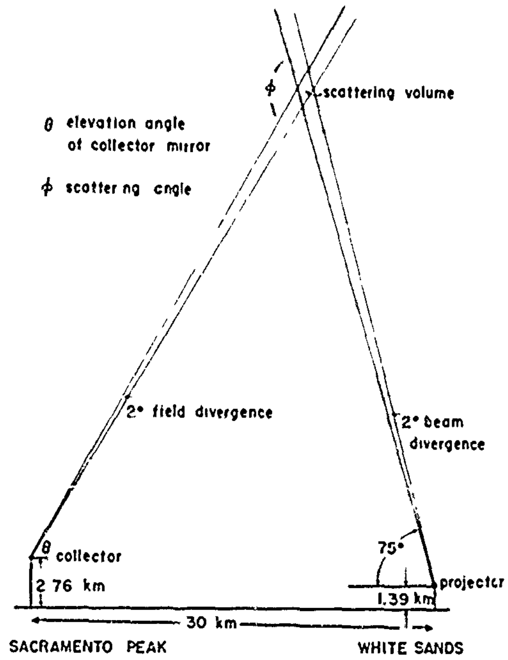
This study was successful in identifying several layers of high aerosol concentration in the atmospheric region below 35 km. One layer occurred at ten km, at about the altitude of the local tropopause, where temperature stops decreasing with altitude. (Atmospheric parameters relevant to the study, such as wind, density, and temperature measurements, were recorded during the searchlight experiments by radiosonde balloons.) The tropopause aerosol maximum was unexpected, and further studies to investigate this anomaly are planned. A second, and larger aerosol concentration was found at about 19 km where the aerosol layer tends to reach a maximum. This result was in good accord with those of other experimenters. Above 19 km, aerosol scattering rapidly decreases, and by 25 km, almost all scattering is molecular scattering.

Since aerosol scattering plays an important role in the optical properties of the atmosphere's lower region, the AFCRL searchlight study is making significant contributions to an understanding of these properties. The Laboratory is now monitoring these aerosol layers by the searchlight method on a regular basis, in order to allow for daily and seasonal variation. A new treatment of the data obtained from this study promises to provide information not only about the optical properties of the atmosphere, but also about physical properties of the aerosols themselves. The use of lasers instead of searchlights for this purpose is also being investigated.

THE SOLAR AUREOLE: The bright white region around the sun's disk, due to aerosol scattering on hazy days, is called the solar aureole. AFCRL scientists are using the solar aureole to determine the forward scattering properties of atmospheric aerosols in a manner similar to the searchlight method of measuring their backscattering properties.

Measurements of the solar aureole are made by blocking out the sun's disk and measuring the intensity of light in its surrounding halo as a function of the angle between the aureole and the sun. Such a study is not only useful in determining the forward scattering properties of atmospheric aerosols, but also in correcting errors in the measurements of pyroheliometers — devices for measuring the rate at which solar energy is received at the top of the earth's atmosphere. These errors arise from the fact that the intensity of sky brightness is not uniformly distributed, but reaches a maximum at the sun's position. The actual distribution of sky brightness is determined by solar aureole measurements, and can in turn be used to correct pyroheliometer errors arising from this source.

A CLEAR STANDARD ATMOSPHERE: For some time, optical physicists have recognized the need for some kind of standardized "clear atmosphere" with which to compare the optical properties of real atmospheres. Actual conditions in the atmosphere, particularly those affecting its optical properties, vary greatly with weather and other influences. During the reporting period, an AFCRL scientist formulated a "clear



Several layers of high aerosol concentration in the atmosphere were identified by means of this AFCRL experiment. Relative aerosol abundance is proportional to the amount of light backscattered from a searchlight beam and detected by a telescope scanning along the beam.

standard atmosphere" which deals quantitatively with important optical properties of the atmosphere. The text and tabulations that comprise this work actually take on the function of an "Atmospheric Attenuation Model" in the ultraviolet, visible and infrared regions for altitudes from sea level to space.

Attenuation is due to absorption and scattering, with scattering being the greater contributor. Atoms and molecules of various substances absorb some of the light which strikes them and convert it into a different form of energy. In air molecules, this absorbed light is converted into rotational, vibrational, and thermal kinetic energy. This absorption takes place at certain wavelengths, which must be determined experimentally. In the wavelengths considered in the Atmospheric Attenuation Model developed at AFCRL, absorption by atmospheric ozone is included. Although the concentration of ozone at sea level is low compared to that of other atmospheric constituents, it must be taken into account because of its strong absorption of optical energy and its increased concentration at high altitudes.

The other effects, aerosol and molecular scattering, are major attenuators of light travelling through the atmosphere. Little if any light is lost in scattering, but it is dispersed in different directions from that in which it was originally travelling so that scattering has the effect of diminishing the intensity of light along a given path. (The two types of scattering, Rayleigh or molecular scattering, and Mie or aerosol scattering, are described in a preceding section.) All these effects must be combined to determine what the complete atmospheric attenuation will be for a beam of light of a given wavelength. Since atmospheric density and aerosol concentration change with altitude, these factors must also be taken into consideration.

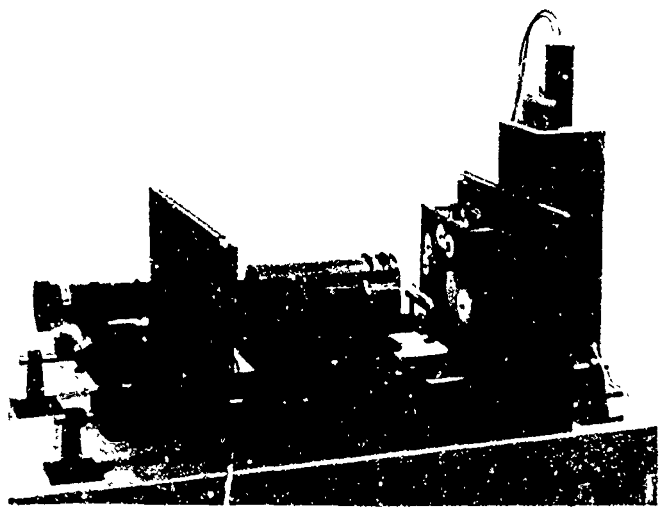
Using atmospheric densities taken from the latest U. S. Standard Atmosphere, (another standard to which AFCRL has made and is making major contributions — see Chapter X), and the best available information on aerosol and ozone distribution, the AFCRL Atmospheric Attenuation Model develops and tabulates aerosol, Rayleigh, and ozone attenuation coefficients for 22 wavelengths from .27 microns in the ultraviolet through four microns in the infrared, including many wavelengths in the visible spectrum. The report in which these tables appear also contains formulas for calculating: 1) the transmission of the atmosphere in a horizontal direction at any altitude, 2) its transmission along a vertical path from any altitude to any other altitude, and from any altitude to infinity, and 3) its transmission along slant paths in any direction. The AFCRL Atmospheric Attenuation Model is recognized as an important tool for basic research and applied problems in the area of atmospheric physics.

In addition, an important theoretical study to determine the optical relationship between multiple molecular scattering and aerosol scattering is being conducted at UCLA and the University of Mainz in Germany under AFCRL sponsorship. To have reached this state of analysis represents considerable progress since it has been only recently that the numerical solution of multiple molecular scattering has been available. The mathematics of molecular-aerosol scattering interactions is very complex and solutions must be based on approximations. Thus the continuation of accurate measurement of both aerosol distribution and the distribution of optical radiation in the atmosphere is necessary for confirmation or modification of these mathematical solutions.

TARGET LOCATION UNDER LIMITED VISIBILITY: An example of a problem in atmospheric optics which is closely related to an Air Force requirement is that of target location under limited visibility. A flight commander who must determine on the basis of visibility whether or not to order a tactical mission, must have a quick and reliable method for making this determination. Some of the factors that must be taken into account in deciding whether visibility on a given day will allow a successful mission include atmospheric conditions, time of day, and target background among others. These determine the distance, or visibility threshold, at which given targets can be seen and identified by a pilot.

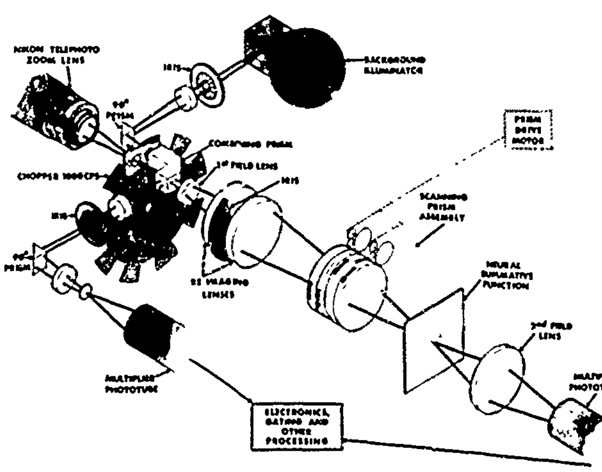
During World War II and afterwards, the establishment of visibility thresholds for a wide variety of targets under all environmental conditions involved scores of test subjects spending countless hours identifying objects in slide projections which attempted to duplicate given visibility conditions. In this laborious manner, a target-visibility index which allowed commanders to look up the visibility threshold of a target, was compiled.

To eliminate the costly man-years of work involved in this kind of compilation, AFCRL has sponsored a study by the University of California's Visibility Laboratory which is aimed at automating the determination of visibility thresholds. This project was successfully completed in the spring of 1964, and a comprehensive report of the results was under preparation at the conclusion of the reporting period.



Automatic indexing of target visibility under a wide range of varying factors is made possible by this mechanical-optical array — one of two systems developed for AFCRL by the University of California to eliminate the need for time-consuming subjective evaluations of target visibility. With this apparatus, the effects of various backgrounds, times of day, and atmospheric conditions on target visibility can be simulated and the results handled by computer.

EXPLODED VIEW MECHANICAL-OPTICAL



In the first of two techniques which were developed in this study, a zoom lens is used to project an object, its model or its photograph, onto a transparency. The transparency has a variable transmission which is proportional to a chosen visual weighting function. A photo-multiplier tube intercepts the transmitted radiation and its output is proportional to the combined effect of this point object and the weighting function element. Rotating prisms transfer the image of the object space across the weighting function transparency. A second channel performs this same action for the background. The channel outputs are differenced to obtain the visual signal.

The other technique uses the projection of a photographic image onto a screen. Centered in the screen is a small variable aperture. The transmitted light is received by a photomultiplier tube. Its output, properly digitized, is recorded on IBM cards.

The chosen weighting functions are also converted to computer language. The computer prints out the signal level for target indexing.

The computer must have stored on magnetic tape a large library of data concerning atmospheric effects typical of conditions in the operational area. The computer must also have available information concerning the optical properties of the terrains which constitute the target background. The computer program must include the dynamic aspects of the observer's environment. With the system, very comprehensive tactical problems can be studied quickly and inexpensively.

INFRARED RADIATION STUDIES

AFCRL's research involving infrared radiation can be divided into three general areas of study. The first concerns the interaction of infrared radiation with the atmosphere, primarily in the form of absorption. The second deals with the use of infrared radiation to detect and identify targets by means of the infrared "signatures" produced by launch and reentry vehicles. The third area involves the optical and infrared backgrounds, such as natural and nuclear induced airglow, against which targets must be detected and identified.

During the past two years some of the Laboratory's more notable progress in infrared research included: 1) the first study of the fine structure of ozone absorption in the 9.0 micron region, 2) the first study of infrared airglow emission, particularly that produced by hydroxyl ion formations, 3) successful continuation of the program for measuring the infrared radiation of launch and reentry vehicles, and 4) the development of several infrared measuring devices for a variety of applications including use in unmanned satellite measurements and Project Gemini experiments.

OZONE AND OTHER ABSORPTION SPECTRA: During the reporting period most of the Laboratory's work in absorption spectroscopy was devoted to a detailed study of ozone absorption between 8.5 and 10.0 microns in the infrared. Ozone is an important atmospheric constituent, and, although the general nature of its absorption in this spectral region has been known for some time, its fine structure remained undetermined until the AFCRL study. By the end of the reporting period, the essential constants required to determine this structure had been established.

Two factors contributed to a solution of this problem: 1) the availability of exceptionally high quality spectra with the Laboratory's high resolution spectrometer, and 2) the extensive use of high-speed digital computers to handle the otherwise unmanageable computational work involved in the analysis of an asymmetric molecule of this type. Approximately four thousand individual lines are produced when ozone absorbs infrared radiation, converting the radiation to rotational-vibrational energy. Manual computation of the frequencies and intensities of these lines would be a task of prohibitive proportions.

Although there are two vibrational bands contributing to the ozone absorption spectrum in the 8.5 - 10.0 micron region, one is considerably stronger than the other. As a result of the Laboratory's study, it was discovered that there is a strong interaction between the two which produces serious intensity anomalies in the weaker band, and, in fact, accounts for the characteristic features of that band. In addition, the constants obtained in this study have made possible the computation of theoretical absorption contours which agree with the observed contours to well within the margin of experimental error.

A second program in this same general area is concerned with the measurement of the absolute intensities of infrared absorption bands. The very weak near infrared bands of carbon dioxide were measured by the pressure broadening technique. (This is a technique in which absorption bands are broadened by placing the absorbing gas under very high pressure.) Ozone and water vapor band intensities are being determined by measuring their optical dispersion. Observations obtained with the interferometer built for this purpose indicate that refractive index determinations accurate to 2 parts in 10 million can be achieved.

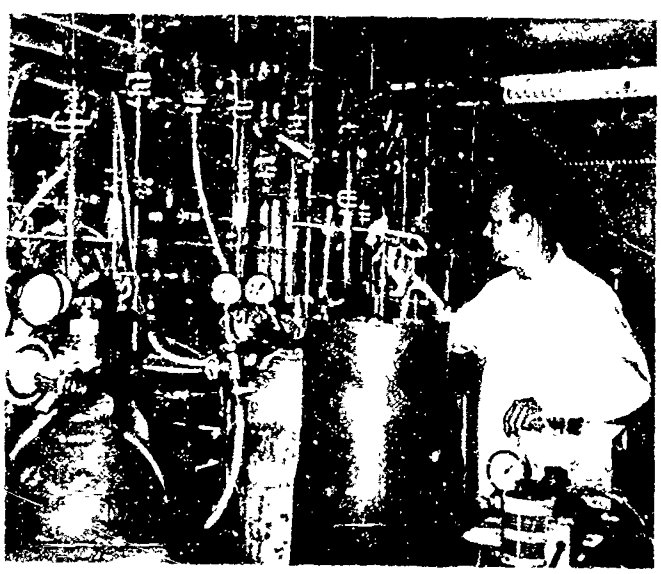
ROLE OF HYDROXYL ION IN AIRGLOW: One "background" which occurs in the infrared aerospace environment is airglow — the faint luminosity of the sky seen on a dark night, but which is of course also present in the daytime. (Other airglow studies are conducted by the Upper Atmosphere Physics Laboratory. See Chapter III.) Airglow refers to optical and infrared radiation produced by chemical reactions between molecular constituents of the upper atmosphere. These reactions may be generated by solar radiation or by high speed particles from the sun or space. They may also be generated by a nuclear detonation in the upper atmosphere. A study of the infrared emission spectra of airglow reactions is being conducted.

During the two year reporting period, an important contribution to the understanding of airglow phenomena was made by the Laboratory. The fundamental emission sequence of the hydroxyl ion, the ion which is responsible for the most intense airglow emission, was observed. This fundamental sequence refers to the hydroxyl ion transitions from highly excited vibrational energy states to the next lower state in which the energy lost in going from the higher to the lower state is emitted in the form of infrared

The fine structure of the ozone absorption spectrum around 9.0 microns was first determined by AFCRL scientists. In this chart of ozone absorptions the upper profile was observed experimentally, while the lower profile was calculated from theory.

radiation. The fundamental emission sequence of the hydroxyl ion had not been previously observed in airglow because the emitted radiation is in the infrared between 2.5 and 5.0 microns and is drowned out by the high level of infrared "background noise" in the region of the atmosphere where the airglow reaction occurs. The AFCRL measurements of this sequence were made by producing OH in a Laboratory reaction.

The type of energy transitions which produce hydroxyl emission are transitions among vibrational and rotational levels of the ground electronic state. In the case of the hydroxyl ion and other molecules, there are only a certain number of allowed quantum levels of vibrational energy. For simplicity, these levels are given numbers. During the AFCRL study, the fundamental emission sequence of the hydroxyl ion up to the transition from the 9th to the 8th vibrational energy level was observed. This transition produces infrared radiation with wavelengths around 5 microns. The transition from the 10th to the 9th level, however, was not observed.



Infrared airglow has been observed for the first time in this AFCRL experiment. The above apparatus is used to produce and measure hydroxyl emissions, which constitute the most intense airglow. These emissions are produced when hydroxyl ions, formed by the reaction of ozone and hydrogen, go from excited energy states to a stable state.

This work has led AFCRL to formulate the following explanation of one of the chemical reactions producing airglow: Atomic hydrogen, which is relatively abundant at high altitudes, reacts with ozone to form hydroxyl ions and molecules of diatomic oxygen. The hydroxyl radicals formed are in an excited vibrational energy state and make transitions to more stable energy states, emitting their excess energies in the form of optical and infrared radiation. A given hydroxyl ion may jump anywhere from 1 to 7 levels at a time in going from an excited to a stable energy state. However, the highest level of energy to which it can be excited by the reaction described above is the 9th vibrational level. This accounts for the fact that the 10-9 transition was not observed in the AFCRL study.

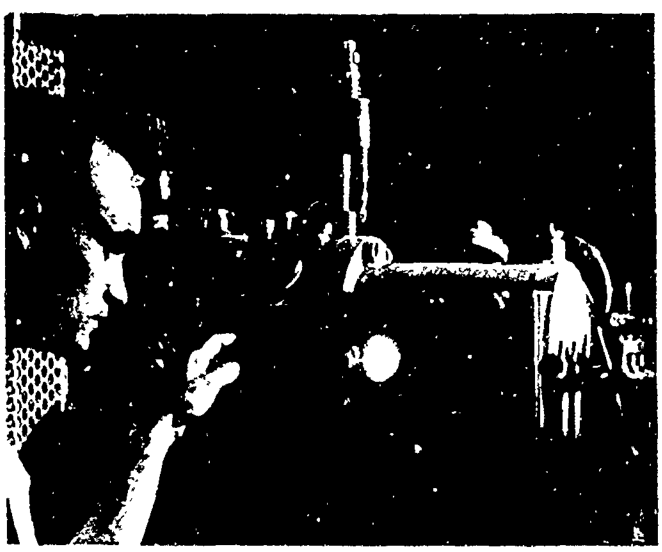
OTHER AIRGLOW-PRODUCING REACTIONS: The phenomenon just described is one of a number of chemiluminescent reactions between atmospheric gases. Other airglow-producing reactions occur between atomic nitrogen and ozone, atomic nitrogen and molecular oxygen, nitric oxide (NO), and atomic oxygen, and atomic nitrogen and nitrogen dioxide (NO_2). The emission spectra of these reactions in the infrared beyond 1 micron were studied for the first time by AFCRL scientists during this reporting period. Preliminary observations showed disagreement with the generally accepted reaction mechanisms for these systems, but not enough data have been taken so far to draw further conclusions. These preliminary observations have, however, pointed up the effectiveness of infrared emission spectroscopy as a tool for identifying the types of radiating gas molecules unambiguously and without disturbing the systems as do other methods such as mass spectroscopy and chemical identification techniques.

The next goal of this research is to determine the dipole moments of emitting hydroxyl ions and other chemiluminescent species. The hydroxyl ion fundamental emission spectra sequence was obtained with a resolution of ten wave numbers, which is not quite sufficient to get accurate integrated intensities from which to make dipole moment calculations. A molecule with a dipole moment has a negative charge at one end and a positive charge at the other, due to an asymmetric distribution of its protons and electrons. The size of this dipole moment depends on the distance of charge separation and the magnitude of the charges at each end. Dipole moments affect both absorption and emission spectra, and thus can be calculated from these spectra, allowing scientists to deduce the structure of a molecule from a study of its spectrum.

To obtain greater resolution with sufficient "light gathering power" in the measurement of infrared spectra, the Laboratory has developed a field-widened interferometer for the 2-12 micron region. In addition to this, the possibility of increasing the resolution of an interferogram beyond its generally accepted limits was studied. The technique for doing this would make use of an analytic property of the data itself, rather than depending on the path length provided by the instrument, and would provide a resolution which would be limited only by the signal-to-noise ratio in the radiation being studied.

NUCLEAR-INDUCED BACKGROUNDS: During the past reporting period, the nuclear-weapon-induced optical and infrared backgrounds measured during Operation Dominic, part of the 1962 series of nuclear tests in the Pacific, were reduced and analyzed to the point where comparisons with natural backgrounds and effects on defense systems could be accomplished. (A large part of the Laboratory's effort during the previous reporting period was devoted to Operation Dominic, and the extensive measurement program which the Laboratory carried out during this test series is described in detail in the previous report.)

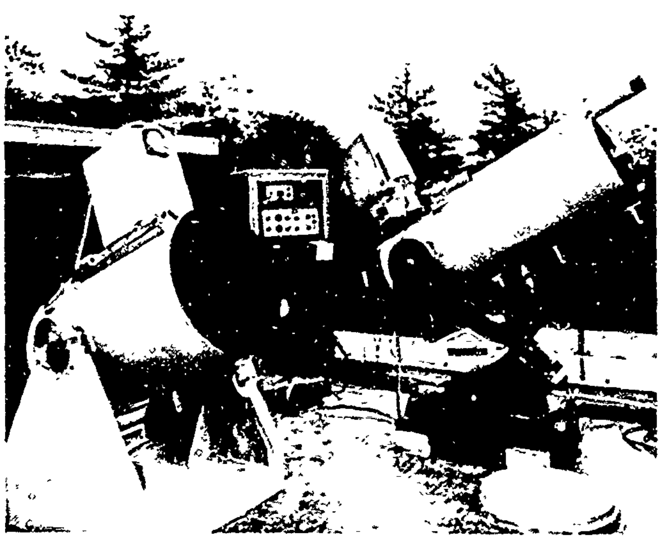
During this reporting period, the AFCRL study of radiant exposure from high yield nuclear detonations was expanded to include studies of specific tactical techniques, both offensive and



In this chamber, airglow emissions are produced by bombarding atmospheric gases with a stream of electrons.

defensive, of interest to the Air Force. A machine code, which takes into account weapon output, height of detonation, atmospheric transmissivity, cloud effects, and target characteristics, was written. This code will allow predictions of tactical effectiveness to be made by computer.

INFRARED CELESTIAL BACKGROUND: To study the nighttime infrared background radiation of the sky, most of which comes from the stars, a multiband stellar photometer has been developed, and has been used to obtain spectral energy distributions for a number of stars in the wavelength region between 3500 angstroms and 2.2 microns. This program is currently being extended so that a large number of stars, whose predicted emissions are strong in the infrared, can be studied. Concurrently, data pertaining to atmospheric transmission of infrared radiation during nighttime hours are being collected. Such data — which are essentially concerned ' .th atmospheric attenuation of infrared energy — provides an indication of the stability and homogeneity of the atmosphere. It also provides a means of checking the validity of atmospheric transmission models.



Two infrared telescopes atop AFCRL laboratory building at Hanscom Field are being used to map sources of infrared energy in the sky. Most of these sources are stars.

LAUNCH AND REENTRY RADIATION: During the period, AFCRL continued studies to determine the spectrum of wavelength and intensity of infrared radiation given off by particular types of missiles during both the launch and reentry phases of their flights. Such a study is useful to the Air Force because of its importance to optical and infrared missile detection and tracking techniques. Both the plumes of rocket exhaust which missiles trail as they ascend, and the glowing of reentering nose cones can be considered "signatures" of the missile or nose cone, and can be helpful in discriminating between friendly and enemy missiles, and between real and "dummy" warheads.

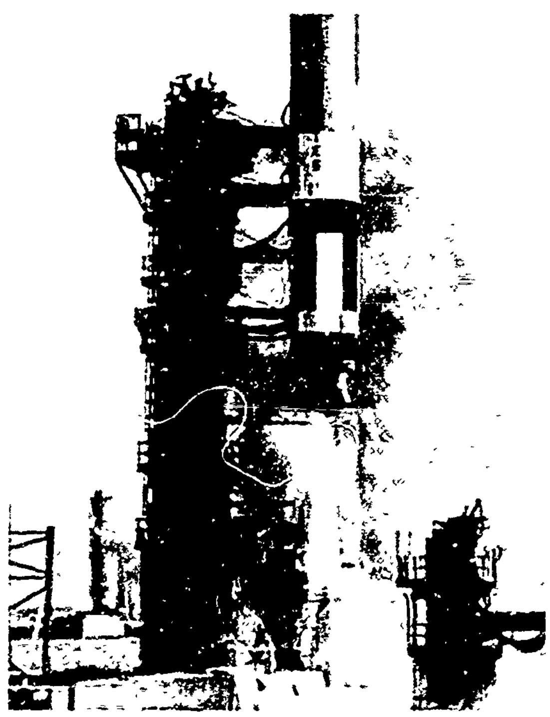
During the launch phase of its flight, a missile plume of exhaust gives off a spectrum of infrared and optical radiation which is characteristic of that particular missile. The difference between the radiation spectra of different missiles results from their different nozzle shapes and their burning of different fuels. Measurements of missile plume radiation can also yield important information on engine efficiency. In addition, such measurements provide an experimental basis for more theoretical studies of the optical and infrared radiation produced during chemical combustion. These studies, in turn, can give insight into the reaction mechanisms of combustion.

During this reporting period, several series of flights to measure the radiation of various missile plumes were completed. These included the successful completion of the scheduled series of four Atlas flights, six Titan II flights, and two Agena flights. None of the three Centaur flights which were scheduled as part of this program have been flown to date.

The pods carried aboard the Titan II flights are a good example of the type of instrumentation used in the missile plume study. On each Titan were mounted two cylinders about one foot in diameter and three feet long. Each cylinder contained four infrared spectrometers covering the spectrum between 2.3 and 4.6 microns, three infrared radiometers, and a three-axis magnetometer for determining the orientation of the cylinders as they fell through the Titan's exhaust plume. The first pod was released at 300,000 feet and the second at 600,000 feet. Two infrared radiometers were also mounted on each Titan II so that they pointed downward toward its exhaust plume. These radiometers covered the same spectral region as the sensors in the drop-out pod, and thus made it possible to compare the radiation spectra outside the plume with the spectra inside it. The drop-out pods contained their own power supplies and telemetry systems, and radioed their data back to various tracking stations along the Atlantic missile range. Similar instrumentation, with minor variations, was used in the studies of other missile plume characteristics.

Much less is known about the spectra of optical and infrared radiation emitted by missile nose cones during reentry. Nose cones, like meteors, become white-hot during reentry because of atmospheric friction. A nose cone gives off particular kinds of radiation which can indicate the kind of material it is composed of. Thus the radiation emitted by nose cones during reentry can be used as a "signature" by which to identify them as friendly or enemy, and also to distinguish between real and "dummy" warheads. In addition, this radiation can be used to study the properties of the plasma sheath that surrounds vehicles reentering the earth's atmosphere.

During this reporting period, optical and infrared sensors designed at AFCRL were placed aboard various reentry vehicles, and data on the radiation they emitted during reentry were telemetered to receivers on board aircraft and ships in the reentry area. The instruments used in this program



Infrared radiation from a rocket's exhaust plume can serve as a "signature" for identifying the vehicle, and as an indicator of engine efficiency. The Laboratory has instrumented a number of different vehicles, including the Titan II shown here, to study their infrared characteristics.

included radiometers, spectrometers, Langmuir probes, impedance probes, and conduction gauges, in addition to the pressure, ablation, and motion sensors usually included as part of a reentry test vehicle's instrumentation.

Nine of these specially instrumented nose cones are scheduled to be flown in the program. To date, three of these have been flown. A follow-on program will utilize film recording sensors on board recoverable nose cones.

LASER PLASMA PROBE: Novel instrumentation for studying the plasma sheath which surrounds aerospace vehicles reentering the earth's atmosphere is being developed by General Electric under contract to AFCRL. The instrumentation includes a laser probe to measure the electron density in the flow field of a reentering hypersonic vehicle. Simultaneously, and at the same points where electron density is measured, it can also measure the electron temperature of the plasma. It does this with high resolution in portions of the flow field of interest. It does not disrupt or modify the flow field, and it has application to other plasma diagnostic requirements.

A ruby laser transmits a small (½ inch diameter) beam of monochromatic light through the plasma. At a point of interest along this beam, a spectrometer and sensitive photomultiplier tube observe the Doppler-broadened scattered energy. These observations are then recorded on photographic film by means of an oscilloscope and camera.

The need for an improved plasma diagnostic probe has been recognized for some time. Devices such as the classical Langmuir probe or microwave interferometer have certain undesirable effects when used to measure electron densities or temperature in a plasma. The Langmuir probe sets up a shock wave of its own and might burn off in a hypersonic flow field. Microwave interferometers lack resolution. The interferometer technique can only measure average electron density providing no details on the variation of inhomogeneous plasmas.

The ruby laser plasma probe can measure the electron density distribution with a resolution of a cubic centimeter or less. It uses a 0.30 joule, Q-spoiled laser with a 1-cm diameter beam and a pulse duration of 30 nanoseconds.

The highly promising probe is still under Laboratory test, and development has not yet reached the point of implementation.

INFRARED DEVICES: Work on the development of techniques for exploiting the far infrared region has continued during the reporting period. A new lamellar grating mount and grating drive system was designed and constructed, and a liquid helium-cooled far infrared detection system which can use either carbon bolometers or doped germanium bolometers was built. (A bolometer measures the intensity of infrared radiation striking it by changes in its resistance.) In addition, measurement of the far infrared reflection spectra of semiconductor materials was begun. The spectrum of magnesium stannide has been determined.

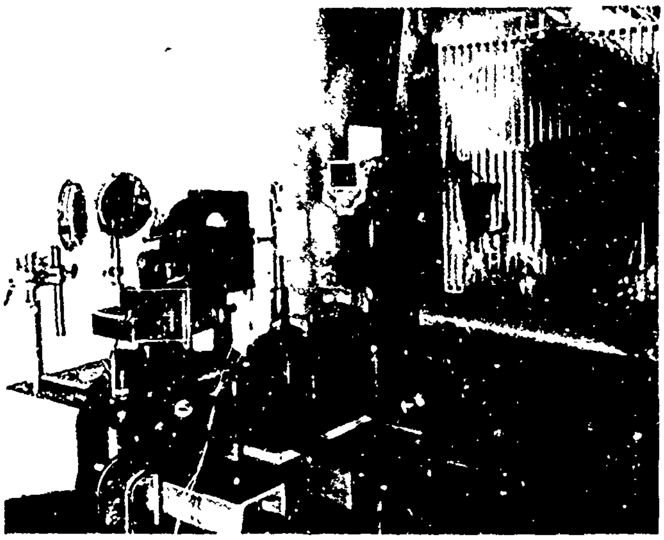
In another area, a field widened interferometer has been developed which successfully employs the principles of optical heterodyning to reduce the information band width necessary to produce spectrograms from the Fourier transformation of interferograms. This instrument has been used to obtain spectra of extremely weak, diffuse sources of helium emission.

Studies have also been carried out on the effects of the state of coherence of radiation on the spectral scanning function of conventional spectrometers used to analyze this radiation.

The development of effective horizon seekers for the stabilization of spacecraft and satellites is a prime research objective of the Laboratory. This objective led to an extensive series of observations of the radiation emitted or scattered in the vicinity of the earth's horizon. From these measurements, the Laboratory hopes to determine the optimum spectral regions around which effective satellite horizon seekers could be designed. To carry out the study, the Laboratory developed a satellite-borne spectroradiometer which measures the radiation gradient of the horizon with a spatial resolution of 1/10 of a degree throughout the spectrum from 2000 angstroms to 40 microns.

UNMANNED SATELLITE MEASUREMENTS: During the reporting period, the first measurements using an interferometer-spectrometer aboard a satellite were made. The AFCRL-designed sensor was pointed toward the earth and measured infrared radiation in the 5 to 15 micron region.

Sensors to cover a much broader spectral range have been designed by the Laboratory to be carried aboard the OV (Orbiting Vehicle) series of Air Force satellites. Each will carry a variety of experimental packages for general environmental studies (many of these packages designed by scientists in other AFCRL laboratories). The Optical Physics Laboratory has designed a number of optical and infrared radiation sensors that can measure radiation across a very broad spectral range extending from 2000 angstroms (0.2 microns) in the ultraviolet to 30 microns in the far infrared.

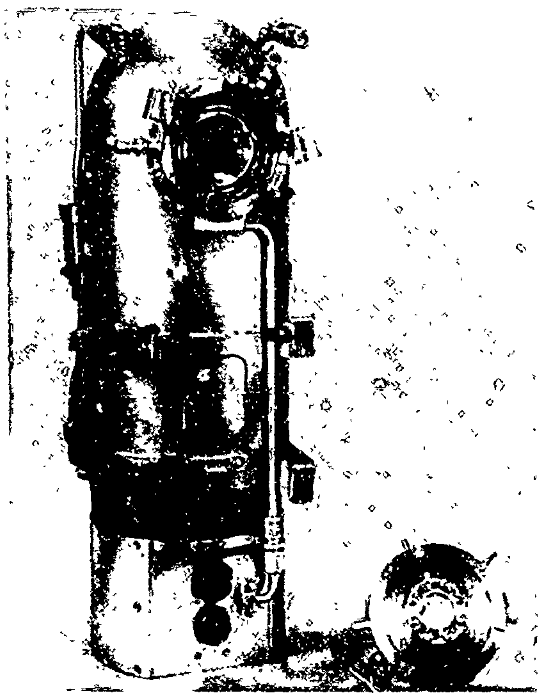


This new far-infrared spectrometer with lamellar grating (shown at right) will be used by AFCRL scientists to study the electromagnetic spectrum between 50 microns and several millimeters.

The first satellite in the OV series, OV-1, was launched on 21 January 1965, from Vandenburg AFB, California, but failed to achieve orbit. The program calls for a total of seven launches in 1965 and 1966.

PARTICIPATION IN PROJECT GEMINI: During the Gemini 5 and 7 flights, both scheduled for 1965 launch, project astronauts will perform a series of optical experiments designed by AFCRL. Spectral and radiometric measurements of the distribution of radiant energy will be made of the earth and sky backgrounds and of the radiation emitted by a missile during launch and in flight. Measurements will also be made of radiation emitted by an object ejected from the Gemini vehicle, and by individual celestial bodies such as the moon, and a star or planet.

During the period, AFCRL designed the instruments for these experiments



This cryogenically-cooled infrared spectrometer, developed by AFCRL to be carried aboard Gemini 5 and 7, will be used by astronauts to measure radiation from objects in space, such as the target shown in front of a Gemini capsule in the illustration below.

and integrated them into the spacecraft. A special handbook of instructions for the Gemini astronauts who will conduct the experiments was also prepared. AFCRL will perform the data reduction and analysis after the experiments have been performed.

The devices to be used in the experiments include: 1) a 30 filter radiometer that can cover from 0.2 microns in the ultraviolet to 20 microns in the far infrared, 2) a dual interferometer-spectrometer that can scan from one to three microns and from three to 13 microns simultaneously, and 3) an 8-13 micron interferometer-spectrometer that is cryogenically cooled by liquid neon — the first time a cryogenic system has been used aboard a satellite. It will be used to measure the spectral distribution of radiation emitted by a target ejected from the Gemini vehicle.

LIGHT SOURCES

The Laboratory is investigating two types of light sources. The more familiar of the two is the laser. The laser research program is not concerned with laser devices as such — but with understanding fundamental laser properties.

The other source, a unique and highly efficient arc-light, was put to a number of uses, including use as a light source for high speed, high repetition rate photography. Work on this light was begun before the laser was invented in the hope that it could be used as a light source for an optical radar system. Although its application in an optical radar system is no longer actively considered, the AFCRL arc-light has found several other applications in both research and applied technology.

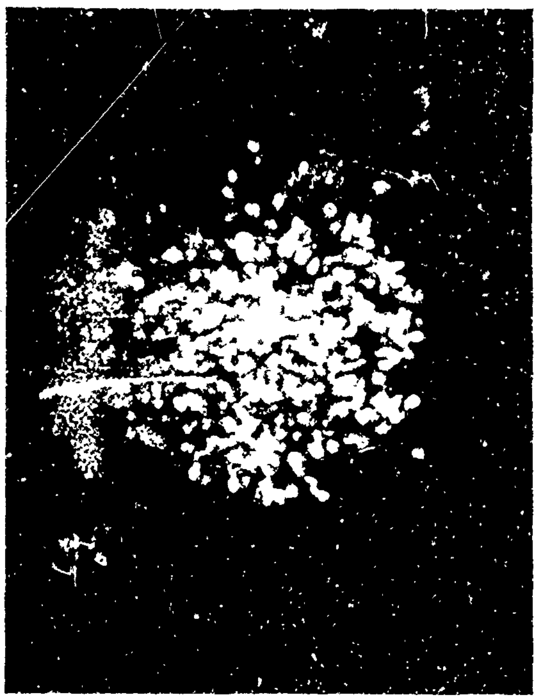
LASER DYNAMICS: Most of AFCRL's laser research involves experimental and theoretical studies of optically-pumped solid lasers. During the last reporting period, the focus of this research was the study of high-order transverse modes (those in which the distribution of light in the laser has nodes on any plane perpendicular to the light beam) in ruby lasers. This study greatly clarified the relationship between the optical quality of a laser material and the generation of beat frequencies by the interference of different modes. The experimental work, which involved several techniques for examining the output of a laser, resulted in a significant advance in the understanding of the oscillation process in plane-mirror lasers.

During the past two years, the Laboratory's laser research has shifted to
2 a study of solid lasers having a spherically curved mirror, instead of a plane mirror, at each end. This configuration is called "confocal" when the mirrors are separated by a distance equal to their radius of curvature and thus have a common focal point halfway between them. The Laboratory's research uncovered, and took large steps toward explaining, some profound, surprising, and initially puzzling differences between the behavior of plane-mirror solid lasers and curved-mirror solid lasers.

Some of these differences are: 1) Beat frequencies produced by the interference of transverse modes and ranging from tens to hundreds of megacycles have been observed in plane-mirror, but not in confocal, ruby lasers. 2) Most unexpectedly, the spectrum of a good confocal ruby laser is continuous and shows none of the sharp lines of a plane-mirror ruby laser's spectrum. (These lines correspond to the different frequencies of the various axial mode numbers.) Furthermore, the total width of the confocal spectrum is only about one tenth that of the plane-mirror. 3) In the confocal configuration, both the aperture and far-field distributions are uniform blobs of much larger extent than would be expected from a consideration of its modes. It turns out that these lasers are not coherent in the same sense as plane-mirror, or the usual gas, lasers. Nevertheless, they have strong advantages for some applications. 4) Perhaps the most puzzling characteristic of confocal solid lasers is that their spiking shows extreme regularity, in contrast to plane-mirror solid lasers which release their energy in a short series of bursts or "spikes" having very irregular intensity and spacing.

This experimentation has led to the development of a theory of confocal laser operation which differs from the theory of plane-mirror lasers in a number of particulars. Both theories rest on the same foundation — an energy balance equation, which describes the relationship between energies carried by the various relevant subsystems of a laser (the excitable atoms, the various electromagnetic cavity modes). But the AFCRL theory reinterprets a single-mode equation to apply it to the highly multi-mode situation encountered in confocal solid lasers. It relates the differences between the plane-mirror and confocal configurations to the fact that plane-mirror operation consists of the oscillation of a few well-defined modes at a time, while confocal operation always consists of a great many modes at a time. The AFCRL theory also applies to non-AFCRL experiments. For example, it appears to explain some recently published results concerning the regularity of spiking of a laser consisting of several flat-mirror rods in series, imperfectly aligned, as well as a remarkable older result — the elimination of spiking in a special curved-mirror configuration.

THERMAL EFFECTS IN SOLID LASERS: Mode hopping, large beam divergence, and high losses are characteristics of ruby lasers. Since these could originate from thermal effects caused by rapid, nonuniform absorption of a large quantity of heat, an extensive program was undertaken to investigate these effects in ruby and glass lasers. The method of measurement involved placing the laser rod to be tested in one arm of a Twyman-Green interferometer and observing fringe shifts versus time with a fast camera as the laser rod (without mirrors on the ends) was being pumped. A confocal ruby laser (described above) was used as a light source, and this proved to be the key to the successful series of measurements.



Output of a confocal ruby laser was photographed to test the validity of the AFCRL theory of confocal solid laser dynamics. Each spot represents light emerging at a particular angle during one "spike" (lasting 50 billionths of a second) of the laser's output.

A convex distortion of approximately one half wavelength was observed in a ¼ inch by 2 inch ruby rod with rough sides when pumped with a helical flash lamp at threshold pumping energy. The distortion becomes much worse if either a straight flash lamp or a laser rod with polished sides is used, since both of these features aid in focusing the pump light to a greater degree in the center of the laser rod. It becomes worse if higher pump energies are used.

Several measurable characteristics in the experiment (total optical expansion, distortion decay time) agree with appropriate heat transfer theory. One other characteristic bears mentioning, however, since it is a new phenomenon in ruby: between 40 and 100 milliseconds after the pump light is extinguished, scattering occurs which is so severe that roughly ¾ of the energy is lost from the probing beam. The striking feature of this is the long delay time before its occurrence. This is not understood and is being pursued further.

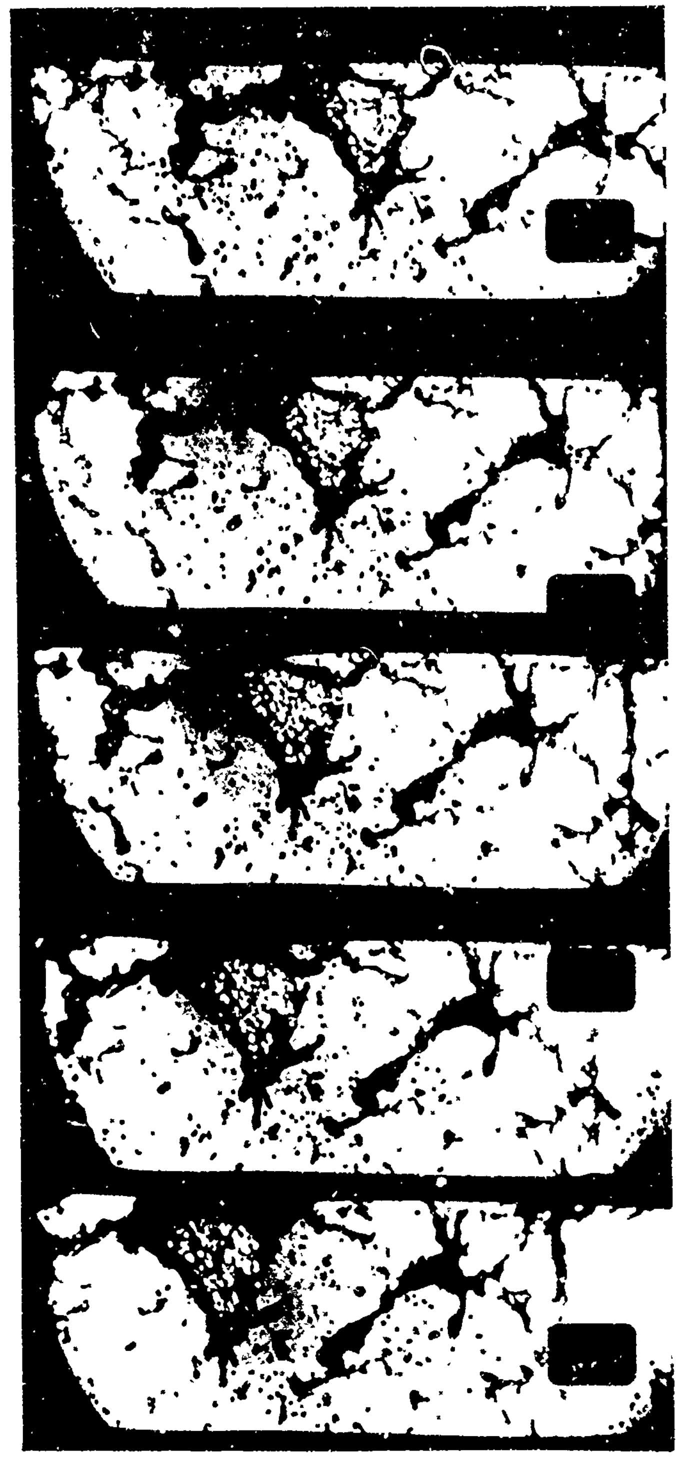
These studies serve to emphasize the necessity of uniform pumping of laser rods if small beam divergence is to be obtained. They also make evident a new phenomenon in ruby which warrants further investigation: thermally induced scattering.

NANOSECOND LIGHT PULSES: A powerful arc-light, which has been under development at AFCRL for the past several years, is finding an increasing number of applications. Called the "Nanolite" because its flash duration is measured in nanoseconds (billionths of a second), this device can generate up to 50,000 short, brilliant pulses per second. The Nanolite represents an order of magnitude improvement over conventional flash lamps for a number of applications, such as ultrahigh-speed photography, which require extremely brilliant, short-duration flashes. In addition, the Nanolite is compact and inexpensive because it doesn't need the complex electronic circuitry usually required for high repetition-rate flashing.

The heart of the device is a novel capacitor capable of discharging its energy in a sudden burst. The resulting pulse has a sharp vertical rise to maximum and an equally sharp decay time. This is a difficult requirement because the magnetic fields generated by electric currents set up inductances which oppose the flow of current and thus prevent a rapid discharge of energy. The coaxial capacitor is almost inductance-free. By varying the capacitance and thus the energy stored in the capacitor, the length of time for a discharge through the arc channel can be varied.

Flashes as short as one nanosecond have been produced. The brightest flashes have a brilliance exceeding 30 million candles per square cm, making the Nanolite the brightest non-laser source yet developed.

Although it requires current densities in the arc channel of over 10 million amperes per square cm to achieve this brightness, the Nanolite has a nearly unlimited lifetime because the extremely short duration of its flashes prevents electrode heating and erosion. This combination of characteristics makes the Nanolite suitable



The tiniest droplets in an atomized water jet show clear definition in this series of ultra-high-speed photographs taken using the AFCRL Nanolite as a light source.

for a wide range of potential applications in addition to high-speed photography. Among these applications are: 1) as a light source for flash photolysis — the study of chemical reactions produced by light, 2) for measuring the response times of photodetectors, 3) for studying recombination phenomena in the afterglow of an electric arc, and 4) its extremely short current pulse can be used to drive diode lasers for a high power output at room temperature, this being an application to which MIT's Lincoln Laboratory has already put the Nanolite.

Recently, the Nanolite was used as a light source for high repetition-rate photography of fluid atomization. The Nanolite is ideally suited for this purpose because of the small size of the particles involved. Although atomized droplets travel at the relatively slow speed of about 100 feet per second, they travel a sizeable fraction of their 0.2 mm diameters in a few hundred nanoseconds. Therefore, exposure times in the 25 nanosecond range are needed to photograph them with a sharp definition.

What makes the Nanolite particularly attractive for this kind of photography, in addition to the short duration of its flashes, is the fact that it flashes automatically up to 50,000 times per second when powered by a simple, compact, battery-operated D.C. source, and that its flashes are equally spaced. This self-pulsing or "free-firing" capability eliminates most of the expense of high repetition-rate photography, which generally goes for the complex electronic circuitry required to produce a series of short, evenly spaced current pulses to power the light source. The strip of pictures which was taken of fluid atomization using the Nanolite for a light source provided an impressive demonstration of its capability in this area. The pictures yielded complete and accurate information on the motions of particles in the spray.

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Test and evaluation of experimental integrated computer circuits is a delicate operation, often requiring jeweler's techniques. The silicon wafer being tested here contains 2200 insulated gate, field-effect transistors.

VII Data Sciences Laboratory

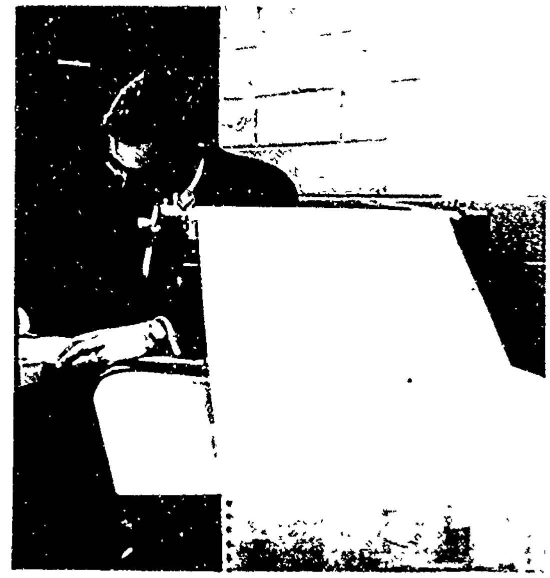
The program of the Data Sciences Laboratory centers on the processing, transmission, display and use of information. Much attention is therefore focused on computers. One important aspect of the Laboratory's computer research program is that of making more effective and efficient use of computers. Computers are capable of many more tasks than they presently perform.

A sizeable segment of the Laboratory's effort is therefore devoted to computer programming and languages. The goals are to achieve more effective man-machine relationships, to communicate better with computers, to improve decision-making capabilities, and to uncover techniques whereby computers can directly assimulate a variety of non-numerical data.

The Laboratory is also looking ahead to future generations of machines. In this general category falls research on biological systems, consisting of studies of the electrical structures of the brain. From this effort, the Laboratory hopes to find clues as to how the brain so effectively collects, processes and retrieves information. The Laboratory is also looking into new computer logic structures. Here, research consists of network analysis and computer logic networks of increased flexibility and efficiency.

The third major category of Laboratory activities, a category that sometimes overlaps the others, is communications — particularly the transmission of audio-visual information. A large continuing effort is devoted to speech research. This research involves both the physiological mechanisms of human speech production and the machine processing of speech signals. One goal of the speech research program is that of transmitting speech over extremely narrow bandwidths. For a similar purpose — that of bandwidth reduction — the Laboratory is investigating television transmissions. Here the goal is to transmit pictures over narrow channels with a minimum of degradation in picture quality. Finally, the Laboratory is investigating the problem of transmitting coded messages with maximum reliability and with minimum redundancy. This work falls into the category of error-correcting codes and error detection.

Data processing techniques and communications are at the very core of most large Air Force systems. The research program of the Laboratory is, therefore, centered on basic technological requirements of the Air Force.



More effective computer programs can greatly enhance the performance of existing computers, resulting in a great saving in computer time. Much of the effort of the Data Sciences Laboratory is devoted to the development of more effective programs.

COMPUTER LANGUAGES

The outstanding computer problem is that of communicating with them. The Laboratory is looking into methods to obtain closer and more natural interaction between man and machine. To improve the man-machine interface, two related lines of inquiry are being pursued.

One of these is the design of user-oriented (as against machine-oriented) programming languages that will provide maximum convenience to the user, and that will permit him to outline his program for machine computation in a language that is as close as possible to the way he would describe his problem in natural language. The objective here is to make him less dependent on the conventional machine programmer.

The second approach is that of developing techniques whereby the user can directly instruct the computer to perform certain operations at various times during the computational process — an approach known as on-line use of computers. This results in close interaction between man and machine, bringing about a cooperative man-machine effort in solving problems.

LANGUAGES IN PERSPECTIVE: This section does not deal specifically with the Laboratory's program, but is inserted to provide background information necessary to an understanding of the kinds of problems the Laboratory is dealing with.

For those outside the field of computer research, few technical areas are more obscure than "computer languages." The very names of the special computer languages — ALGOL, COBOL, FORTRAN, LISP and so on — have an uninviting quality. The unfamiliar terminology used to discuss computer languages — and worse — familiar terminology in unfamiliar context, often leaves the uninitiated reader hopelessly confused. The confusion is compounded by the fact that much of the research on computer languages involves computer analysis, and this analysis brings into play the formulation of special computer programs for the study of these languages.

All internal information in the machine is couched in abstract machine code that has no direct relation to the problem the machine is working on. To run a specific problem on a machine, a scientist not thoroughly familiar with computers will have to use the intermediate services of an analyst and a programmer. The user is in effect separated by a great distance from the machine. To shorten this distance, "problem-oriented languages" have been created to make it possible for the user to state his problem, or, more precisely, specify the desired procedure, to the machine in a form as closely as possible related to the form in which he would state the problem for his own use.

A large number of such languages have come into use, among the best known being FORTRAN (FORmula TRANslation), and ALGOL (ALGebraic Oriented Language). Problem-oriented languages are machine-independent — that is, they can be used by any type of machine. But programs written in a problem-oriented language must nevertheless be translated into the internal language of a particular machine. This is done by compiler programs. Compiling occupies a significant part of the activities of a large-scale machine, often consuming on the order of 30 percent of the useful machine time. Thus, compiling adds considerably to the duration and, therefore, the cost of machine use.

Nevertheless, the advantages of problem-oriented programming languages are striking. First, they bring the computer program into close relationship to the problem as seen by the user; second, one instruction in the programming language text usually implies a large number of individual computer instructions which are automatically detailed in the compiling process; and, last, the use of a proper programming language automates a number of tedious housekeeping tasks which must be done explicitly when programming in machine code.

Problem-oriented languages used to converse with machines are still far remote from ordinary conversation. In fact, some of the major programming language manuals run to hundreds of pages containing vast numbers of rules which have to be followed meticulously.

The goal of present research in programming languages is evident from these shortcomings. Languages should be more universally applicable, thereby reducing the number of languages used, and closer to natural language. Also needed are efficient means of translation from various languages into machine codes as well as from one language to the other. Yet adequate solutions, necessarily compromises, have to be found if computers are to play the roles of which they are capable.

This has led to intensive research in the science of formal languages and their syntax and grammar. Such questions as equivalence of statements in

Development of improved computer languages is a cooperative scientist-computer endeavor. Procedures worked out by the scientist at his desk are later tested, verified, and perhaps improved upon by the computer.

different languages, translatability and relative efficiency, and effective ways of syntactic analysis are in the foreground of present research. One sees that many of these topics are just as applicable to natural language — for example, English. For ideal communication between man and machine, both would converse freely, without translators, in English.

GRAMMARS AND COMPILERS: In the foregoing section, it was seen that a source language — for example, COBOL — must be translated into a form that is acceptable to a particular computer, and that such translation requires compilers. A compiler is usually a machine program designed for a particular type of computer and a particular source language.

If the same source language is to be used with another machine, a special compiler for the second machine must be used, since a compiler developed for one machine cannot usually be used with another. The development of a compiler is a task of large proportions — and costly.

Ideally, one would wish to be able to program any machine in any source language one chooses and, conversely, a given source language should be freely translatable into any needed machine code. By separating those components of the translation process that are common to all translations between any source-target language pairs, and those that are peculiar to a specific pair — that is, the syntactic and lexical descriptions of the languages in question — one arrives at so-called syntax-directed computers. These compilers are adaptable to large classes of source target language pairs with much less effort than it would take to construct special purpose compilers. Work at AFCRL has been proceeding successfully to implement this type of compiler efficiently and economically.

Work in the Data Sciences Laboratory is directed toward the analysis of the rules of formulation (grammars) and the structural similarities of the various source languages — English as well as the artificial languages. Specifically, AFCRL work centers on the following problems: 1) What type of grammar is appropriate to define particular languages and assign to them adequate structural descriptions? 2) What are the theoretical properties of the various types of grammars that are of practical significance? 3) What procedures can be found for efficiently determining the structural description of a language with respect to a grammar of a certain type? and 4) How can the structural descriptions be mapped into equivalent machine code programs?

In the first area, the Laboratory is investigating the utility of context-free grammars in defining current programming languages and the utility of transformational grammars in defining languages closer to English. Transformational grammar is the best descriptor of natural languages, such as English, that has been proposed to date. As less and less restricted subsets of English are considered as possible programming languages, the demand for a formal English grammar that assigns more useful structural descriptions will increase.

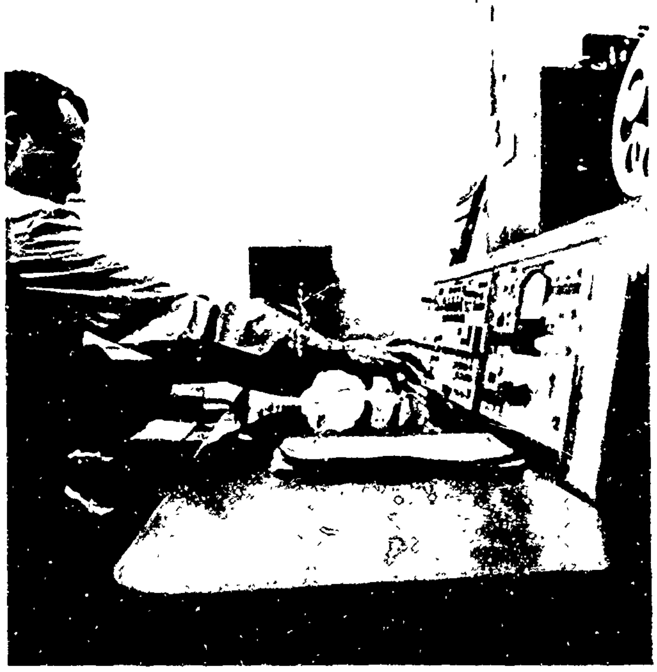
Transformational grammars assign structural descriptions that reflect each of the possible meanings or interpretations of a sentence. In order to use transformational grammar, it is necessary to have a procedure for finding all possible structural descriptions of a sentence. The Laboratory has developed a computer program for doing this which is the first mechanization of such a procedure to have been developed. This program is written in the LISP programming language for the AFCRL UNIVAC M-460 computer. It diagrams a given sentence in all possible ways. The procedure used is general in that it is not merely valid for a particular grammar but is equally applicable to any transformational grammar satisfying certain conditions. Although in its present form it is too slow to permit practical use in an information processing system, the program is useful to linguists engaged in writing and investigating large transformational grammars.

In general, transformational grammars provide essential semantic information with a minimum of ambiguity and grammatical rules. They provide one of the most promising approaches to more natural communication with a computer.

In the second area, investigations have been directed to the considerations of properties of context-free languages and more powerful general rewriting systems. These general rewriting systems provide considerably more descriptive power than the ordinary context-free grammars. In particular, context-sensitive grammars are properly included among the general rewriting systems. The results obtained have application to the construction of recognizers for phrase-structure languages (context-free and context-sensitive).

Several efforts are being conducted in the third area. In one study several of the more prominent procedures for syntactic analysis of programs written in a context-free language were precisely specified in terms of equivalent computer programs. These programs were simulated on the UNIVAC M-460 computer and actual LISP and ALGOL programs analyzed in order to determine the relative efficiencies of alternative context-free recognition algorithms.

ON-LINE USE OF COMPUTERS: For certain kinds of problems, the optimum situation is one in which the computer and the user jointly bring to bear their respective talents on the solution of the problem. In this situation there is close interaction between the computer and the user at various stages of the problem-solving process. Widespread interest has been shown recently in the use of computers in such a manner. Such on-line use of computers requires programming languages permitting easy discourse with the machine. The user must have means to specify his intentions to the computer, and the computer must provide information in a suitable form.



AFCRL's Cambridge computer, by today's standards a rather small and slow computer, has nevertheless been used extensively for research in the translation of artificial languages to more natural user-oriented languages.

This leads again to the development of special programming languages. The Laboratory's program was developed partly as a vehicle for the study of the problems involved in the design, implementation, and use of such on-line programming systems and partly to develop tools useful in attacking other problems. The M-460 computer at AFCRL has been used in all of this work. An assembly-language programming and operating system for the M-460, oriented completely toward on-line use, was constructed. This contains a macro-assembler, editing program, and a flexowriter-controlled debugging program permitting examination and change of programs in assembly language, insertion of program breakpoints, and various other features Building on this debugging program, a more elaborate assembly-language debugging program with quite novel features, was later developed. It permits insertions into or deletions from the program being debugged with appropriate relocation of the remainder of the program.

In the area of higher-level languages for communications between user and machine, a complete version of the LISP programming language with debugging features especially designed for on-line use, such as breakpoints and more selective tracing, was implemented on the M-460. The transformational grammar recognizer mentioned above was developed using this LISP system and was debugged far more rapidly than would have been possible with conventional methods. While debugged on-line, this recognition program itself makes no essential use of interaction with the user.

An example of a program in which interaction is essential is one using LISP to test a context-free grammar and the associated rules. The grammar and translation rules together make up a syntax-directed compiler. The program permits the user to apply his syntax and translation rules to test certain cases. Working closely with the computer, the user can examine the results, modify the syntax and translation rules, test them again, ask the computer to examine special cases and so on, until he has arrived at a satisfactory result. The convenience and economy of this procedure is in striking contrast to conventional procedures.

THEOREM-PROVING: The foregoing is concerned with general aspects of computer languages and programming. Special computer programs are formulated, of course, for a wide variety of specific purposes. Although the focus of the work is not on computer languages and programs as such, the work, nevertheless, provides sharper insight into programming processes. One such program of interest to the Laboratory is that of theorem-proving. Proving theorems in some well-defined theory is an intellectual, even creative task. Where theorem-proving is performed by a machine, the machine may be said to exhibit artificial intelligence, a term applied to any machine performance that in human terms could be said to require a certain amount of intelligent thinking. Nevertheless, a prior condition to this performance is the development of an effective program.

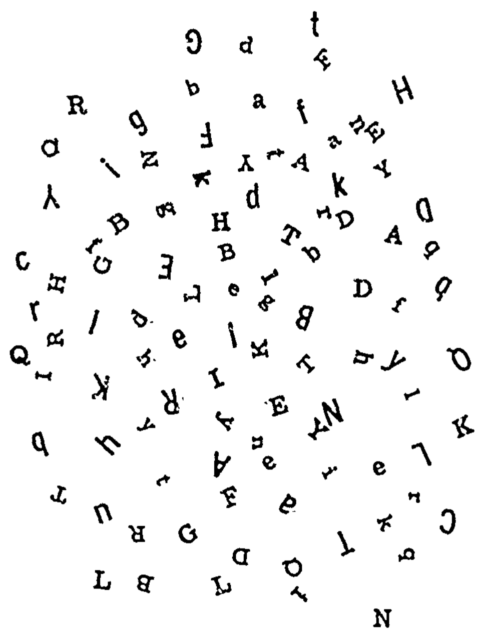
At AFCRL particular attention was directed toward the proof of plane geometry theorems by computer. This field was chosen for several reasons. First, it offers a particular "semantic" heuristic tool. True statements must hold in any example diagram. Inspection of the example diagram helps to eliminate untrue intermediate statements as possible lines for trying to achieve a proof. Also there is an easily understandable interpretation of the Herbrand expansion (a highly formal approach to theorem proving) in geometry. Since the central problem of this approach to theorem proving is the selection of the proper Herbrand elements, this interpretation will greatly simplify the search for effective selection heuristics.

The principal limitation on what can be accomplished is the complexity of the procedures that must be formalized in an effective programming language. The LISP language which has been implemented on the M-460 during 1964 is being used in this research. A program has been written which is capabl of proving easy theorems.

RECOGNITION PROCESSES

Recognition is a prerequisite for man's survival in his environment. By examining a pertinent part of the universe — objects, situations, sound signals — he takes "measurements," receives an "input," and then sees whether his sets of measurements contain certain invariant characteristics, a "pattern," that allows him to classify this input as having a specified significance to him. Humans are extremely proficient at this sort of thing; machines are not. The Data Sciences Laboratory and researchers at other places are heavily engaged in research on various recognition processes.

In attempting to recognize and classify patterns, there is an infinite multiplicity of ways by which objects, situations and physical processes might be described. The primary problem, therefore, is to discover sets of invar-



Character recognition is only one aspect of research on recognition processes. One goal of character recognition is identifying letters of all fonts, sizes and orientations.

iant attributes which describe the pattern or process in the simplest and most effective way according to a set of specified criteria. Both the common attributes of diverse types of sensory data and the distinctive attributes of a particular type of data are sought.

Three Laboratory efforts are directly focused on the problem. These are concerned with: 1) a generalized study of a model for the recognition of visual patterns of all kinds which may have some subtle behavioral analogy to the way the brain recognizes and classifies patterns, 2) techniques for the identification of alphanumeric characters, and 3) general statistical procedures of machine extraction of the invariant attributes of data of all types — visual, electromagnetic signals, meteorological, and so on.

MODEL OF VISUAL PERCEPTION: No mechanism has more tenaciously defied description than that whereby the brain receives, stores, processes and retrieves information. Many models of the mechanism have been postulated. An outstanding common limitation to them all is that none has led to a means for validation through testing. An AFCRL technique which concerns only the processing of visual information is being explored by machine simulation.

The technique was inspired by certain properties of living neural networks — but the resultant model is one which only claims that the brain *could* function in a certain way, not that it does in fact function in the way described by the model. Logically, from the standpoint of the design of equipment for recognizing patterns, it doesn't make too much difference whether the model conforms to actual processes of the brain or not. What is important from the standpoint of application is whether or not the model could lead to an effective pattern recognition technique.

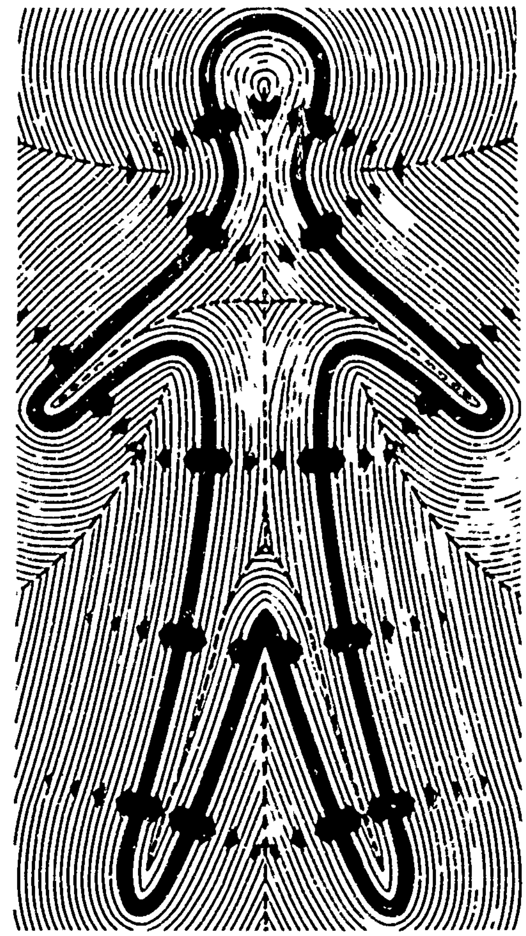
In this model a pattern is not recognized as a whole instantaneously. The original in all its complexity is transformed into a simple residual pattern — but the transformation takes place as a function of time. Knowledge of the rate of transformation of the various parts of the original pattern with time is an essential feature of the model. As a rough analogy of the role of time, one might use the example of music. If all the notes of a score are sounded instantaneously, the pattern of the score becomes meaningless. Only when they occur in ordered sequence, is the score recognized.

One of the basic notions of this scheme is that of a "propagation space" into which the unknown pattern is impressed, stimulating a set of elements in this space. (These elements could be neurons.) From each element the stimulus propagates to its neighbors with a constant propagation velocity, zero attenuation, and a definite time interval during which an element, once stimulated, cannot fire again. Thus, for example, signals emanating from different locations of the input pattern tend to extinguish each other; on the other hand blemishes, such as gaps in normally continuous lines, are eliminated.

Observation of the lines along which extinction occurs as a function of time has proven a powerful tool to arrive at simplified and generalized descriptions of the input object. Complex objects and amorphous shapes that have no simple geometric descriptions — such as clouds — are transformed into a few simple lines. These lines most often bear no resemblance to the original object. The result is a more concise representation of topological features. Although the concept itself is still under study, one specific application is being explored. The process is under study as a means for the automatic analysis of cloud photographs from weather satellites.

The current research program for this study is broken into three main parts: 1) theoretical studies of the basic properties of the model, its capabilities and limitations, 2) search for appropriate methods of implementation, and 3) simulation of the process by special equipment or by computer to arrive at an experimental assessment of the extent of the capability and limitations of the concept.

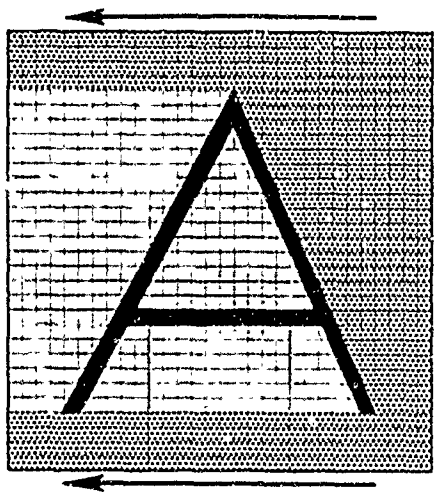
Two simulators capable of making transformations from complex to more simple geometries have been constructed and are currently under investigation.



A pattern transformation process is depicted above in which a figure generates a propagation process analogous to the wavefront of a grassfire. The locus of corners (shown by the dotted lines) and their times of occurrence provide a simple residual pattern which can be used to derive the original figure.

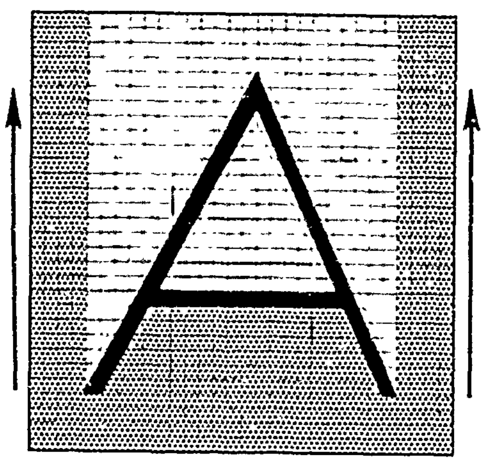
CHARACTER RECOGNITION: Two techniques for the recognition of printed characters, described briefly in the previous AFCRL report, were further refined during the period. Computer simulation and experiments have demonstrated both of these schemes to have considerable power.

The first of these, called the para-propagation classifier, consists of a matrix of identical, intercommunicat-



Horizontal Sweep

One approach to character recognition is the indirect one of examining the residual pattern (unshaded area) that remains after shadowing by the letter itself. Sweeps from different directions yield different residual patterns.



Vertical Sweep

ing logic cells. Initially all the logic cells of the matrix are of the same energy state. The pattern to be classified is read onto the matrix, its outline represented by a change of state of the cells covered by the pattern. One can imagine a 30 by 30 raster of lighted electric bulbs with the letter "A," for example, defined by unlighted bulbs.

The cells are capable of directed, cell-to-cell propagation of change of state, with the propagation beginning at any one of the four outside edges of the matrix and continuing across the matrix. The propagation is blocked at the edge of the letter. The inward propagation is performed sequentially from each of the four sides of the matrix. Only a limited number of letters can be characterized by one series of propagation sweeps. A secondary pattern (which may, for example, consist of the blocked inner circle of a zero) derived from data on the initial tests is then presented for further tests, which are conducted by further inward propagation sweeps. A decision tree governs the process. The testing operations can be combined in tests for an abundance of features of great variety. For example, it was demonstrated by computer simulation that this scheme was able to classify normal upper and lower-case letters with considerable insensibility to variations in type face (such as typed letters versus printed letters as used in standard scientific journals). Assuming a 30 x 30 cell raster (as used in the experiments) and cell switching speeds commensurate with present microcircuitry state-of-the-art, recognition rates of the order of tens of thousands of characters per second appear feasible.

The second scheme, called the Characteristic Loci Classifier, is somewhat similar to the first in that it consists of a matrix of cells. In this scheme each cell in an array looks right, left, up or down, or in any combination of these directions, to see which of these, if any, contains any part of the pattern to be classified. In this fashion, the line of the pattern divides the background into

16 loci, each locus being determined by a four-digit binary code common to its points and to no other points of the background. Of the sixteen possible loci, only eleven are dependent on the shape of the pattern and, of these eleven, only nine are possible if the pattern is connected. For example, the pattern of lower case "a" divides its background into loci whose areas then determine a characteristic vector for the pattern.

It has been demonstrated that alphabetic patterns can be largely categorized by the nine-digit vector composed of the areas. Although the vectors of different alphabetic patterns are not always separable, the separation is excellent in most cases. Since this classifier is very easy to realize (it uses a matrix of entirely combinatorial cells) it may prove useful even though it may not always be capable of complete separation of pattern classes.

DYNAMIC MEASUREMENT PROCESSES: Recognition and classification is most difficult in cases where the data in question result from a dynamic, stochastic process in which the data strongly interact with the environment. AFCRL's effort on dynamic data processing is particularly concerned with this situation. Dynamic measurement processing is concerned with the realtime analysis of sensor data — visual patterns, electromagnetic signals, acoustical phenomena and so on — for the purpose of identifying and extracting from these data certain characteristic attributes. The data from various sensors such as radio telescopes, spectrometers, and ion gauges aboard satellites are often noisy, redundant and difficult to interpret. Interpretation itself is sometimes highly subjective. The information may have different meaning to different observers, depending on their particular point of view and their particular interest. Research on dynamic measurement processes at AFCRL is mainly focused on the question, "What is there that is common to all sensor measurement processes?"

A new theory relating to the measurement and analysis of sensor data evolved at AFCRL. The theory is an outgrowth of a generalized algebra of measurement developed by J. Schwinger at Harvard. It is also closely related to work on general signal analysis by W. H. Huggins at Johns Hopkins, and to a theory of attribute perception by P. Greene at Chicago. Basically, it provides a mechanism for extracting minimal sets of invariant attributes from the raw measurement data. The mechanism used is derived from a small family of principles which any measurement or instrumentation procedure must satisfy. The three most important principles are: 1) reproducibility of extracted attributes, 2) mutual exclusiveness of the attributes, and 3) completeness of the set of extracted attributes.

To evaluate the relative merits of various measurement methods and different pattern recognition and property classification schemes, an extensive signal data manipulation program has been evolved. This program uses AFCRL's Experimental Dynamic Processor (the DX-1), a memory-sharing, polymorphic, digital processor. This program employs the modern technique of representing each signal as a single point in an N-dimensional vector space. Initially, the coordinate describing the signal vectors may be taken as the set of measurements which serve to define the "raw" signal. The investigator is usually not interested in isolated sig-

The Experimental Dynamic Processor (DX-1) is the largest of the Laboratory's five specialized data processors. This processor, a few elements of which are seen in these two pictures, is capable of deriving the characteristic attributes — that is, the often subtle and obscure distinguishing features — of a wide variety of data.

nals, but rather in the mechanism which generates a given ensemble of "similar" signals — for example, EEG signal data, or seismic data — and how this mechanism varies from source to source. One may wish to know, for example, the variations in the electrocardiograph data of individuals with different cardiac disorders, or differences in natural and man-made seismic disturbances. Consequently, the goal of most pattern recognition research is to determine classification procedures which do the most effective job of classifying signals, given criteria of effectiveness.

A key element of the instrumentation is a color display oscilloscope. Since the data classification procedures can be looked upon as transformations of the pattern vectors in the N-dimensional vector space, the display provides an extremely powerful tool for exhibiting just what any given classification scheme is doing. The color oscilloscope is ideally suited for exhibiting the customarily unseen intermediate results. Changes in the point of view from which the process is being observed can be made while the problem is running on the processor. Changes in the processing operation are entered through keyboard control. Functional alterations in the structure of data filters can be also entered directly in analog form by drawing on the face of the oscilloscope with a light pencil. This mode of communication is particularly useful in obtaining a feel for the effect of certain types of perturbation on the performance of the system.

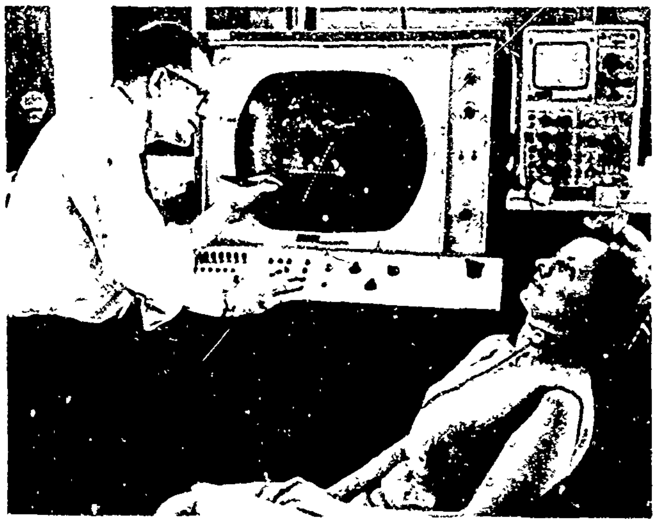
The characterization of signal data through the extraction of intrinsic attributes affords a new approach to data bandwidth compression. The effectiveness of this approach compared with classic approaches, such as Fourier analysis, is well illustrated by a decrease in the number of filter channels (by a factor of ten) needed for a given accuracy of resynthesis.

The price paid for achieving this performance is the complexity of the eigenfunction filter construction procedure on which the intrinsic attribute extraction technique is based. Eigenfunction determination is basic to a class of problems extending from quantum theory to psychological test score evaluation. The central role of eigenfunction determination has led AFCRL to the study of a special processor capable of rapidly and economically determining the principal eigenfunctions of large stochastic matrices. Both electro-optical mechanisms and parallel digital subsystems, operating under the control of an on-line general purpose digital processor, are being investigated.

INFORMATION THEORY

Communications over non-perfect channels and the processing of information through devices that may introduce errors is an unavoidable and permanent condition of Air Force command and control systems. Errors occur and they must be corrected. Such correction is the goal of information theory. Research on information theory in the Data Sciences Laboratory is predominantly concerned with digital coding systems that allow the rate of transmission to approach the capacity of a communication channel without producing an excessive amount of errors.

The key to error-correcting codes is redundancy. If enough redundancy is added to the message it is possible to either detect and correct errors when they occur, or just to detect errors and to reject faulty messages (fail-safe operation).



Analysis of human heartbeats has proved to be a valuable test data input for the DX-1, which analyzes the heartbeat on a real-time basis and performs correlations. During the course of the analysis, the operator may instruct the computer to perform special operations on the data.

PROPERTIES OF ERROR-CORRECTING CODES: The main problem in error-correcting codes is that of knowing what is the "best" error-correcting code to use for a particular purpose. To solve this problem, lesser problems have to be dealt with. One of these is how to tell whether two codes are the same (from an error-correcting point of view). Two codes are judged equivalent if one can be obtained from the other by a permutation of the bit positions. Equivalent codes are the same as far as all error-correcting properties go. The best code is one with minimum length and redundancy, but it is not easy to know which is best. Many codes can be equally "best." Vast amounts of costly computer time have been wasted because there are many codes equivalent to any given one.

In attempting to solve the equivalence problem, the Laboratory considered the case of two codes or vector subspaces that are equivalent under a larger set of transformations, namely, the orthogonal transformations. An orthogonal transformation is a transformation of one vector space onto another which preserves the inner product between vectors. Every coordinate permutation is an orthogonal transformation, but not every orthogonal transformation is a coordinate permutation.

In a study of two vector subspaces over a perfect field of characteristic two, it was shown that there are four conditions that have to be met if two codes are to be equivalent. These conditions are easy to check. As a by-product of the Laboratory's analysis, a rather famous theorem in mathematics — namely, Witt's theorem — was extended to include the characteristic two case. The results for a perfect field of characteristic two have been generalized to a general field of characteristic two.

APPLICATIONS OF ERROR DETECTION AND CORRECTION: Error detection and correction is essential in fail-safe communications — that is, in a mode of operation where messages containing errors are not accepted in their entirety. Maximum fail-safe protection for a given amount of redundancy would be provided if all the redundancy were used for error detection. But it is almost impossible to get any information over some channels because even a single error in a message block causes the block to be rejected. It is therefore necessary to use some error correction along with just enough error detection to keep the probability of accepting messages with errors down to acceptable levels.

Investigated during the past year was a fail-safe decoding technique that corrects errors by erasing the digits most probably in error and filling in the resulting blanks. Calculations show that block error probabilities of less than 10^{-8} are readily obtainable for binary block codes of about 100 digits in length using 50 percent redundancy for the worst possible channel conditions.

In addition to the fail-safe features of this decoding technique, some simplification of decoding circuitry over that usually required for 'maximum likelihood' decoding should be possible. Future plans call for determining the complexity required for circuit implementation.

This fail-safe decoding should be particularly useful when used with feed-back communications. When all erasures are filled in and all parities check, the message blocks are accepted. It is only when an excessive number of erasures occur, or errors are detected, that the feed-back channel calls for a repeat.

Contractor studies of feed-back communication concerned the use of cumulative decision feed-back to lower the threshold of signal-to-noise ratio at which useful amounts of information may be transferred over communication channels. Techniques previously considered discarded the message blocks containing errors but the cumulative techniques save all the information received. Thus two transmissions of the same block might contain errors in different locations so that, although either one of them alone would be rejected, together they can be used to regenerate the correct message.

COMMUNICATIONS OVER SCATTER CHANNELS: Studies of communications over scatter channels were devoted, for the most part, to the overspread channel — that is, to a channel for which the product of fade rate and multipath spread is much greater than unity. One significant result of this study: It was found that for typical error probabilities, a very large spread factor can be tolerated without significant degradation. This assumes that sufficient sophistication is incorporated in the receiver design. Furthermore, even with extremely large spread factors, successful communication can be achieved by using non-binary alphabets.

A study was conducted to establish the upper bound on communication rate over arbitrary fading channels. The result of this study was that with adequate bandwidth to accommodate a sufficiently large number of frequency (or time) diversity branches, the same channel capacity can be achieved as for the infinite-bandwidth nonfading channel. The result is independent of the nature of the fading on the channel, and, furthermore, assumes only a radiometric type receiver.

To see if some of the advantages of non-binary alphabets could be realized on existing scatter circuits, a study was made of easily implemented suboptimum diversity combiners for non-binary (M-ary) transmissions. The study established the performance of a class of diversity combiners which should be instrumentable with digital logic only. Even though these combiners are far from optimum, it is possible to achieve better performance than with binary transmissions.

In designing error-correcting codes for binary transmissions on fading channels, a major concern is the degree of error-clustering since this limits the performance of the code. Experimental determinations of this error-clustering require collection and processing of large quantities of data. To simplify prediction of coding performance a method was established which permits theoretical prediction of the probabilities of various error patterns.

A stained section of a rat's cerebral cortex is magnified 2000 times for viewing on closed circuit TV display. The Laboratory is investigating the electrical activity associated with individual neurons (dark areas) or collections of neurons.

BIOPHYSICAL INFORMATION SYSTEMS

The Laboratory is investigating electrical properties of the brain. Specifically, it is studying what happens when the visual system of mammals is stimulated. Although there is no attempt to construct electronic models of brain functions, results of this work could well lead to new concepts of information processing systems.

INSTRUMENTATION AND PROGRAM: In the reporting period, instrumentation — consisting basically of a highly

Experimental room, shielded from outside EM interference, is used for experiments on electrical activities in the brains of rats. Output data from electrodes placed in the brain lead to the LINC computer (lower photograph) for analysis.

specialized computer — for studies of electrical activity in the rat's visual system was completed. A full-scale experimental program was begun. Thus a milestone was reached in an effort that had its beginning in 1959. Choice of the rat as an experimental animal grew out of several considerations. The complexity of its visual system is relatively less than that of the highly organized system of a cat or monkey. The rat's system is somewhat closer to a "random net" with respect to processing visual information. The rat's cerebral cortex, in addition, does not show the convolutions typical of higher animals since its surface area relative to its volume is smaller than that of higher animals. This "smooth brain" simplifies certain neuroanatomical studies. It also makes possible — in principle at least — studies of the way in which the visual field is mapped on the cortex.

Microelectrodes used to pick up such signals have been refined by development in the Laboratory of a reliable technique for coating etched tungsten electrodes with glass for insulation. A small portion of the glass coating at the tip is later removed by hydrofluoric acid or by spark discharge.

Most experiments involve implanting microelectrodes into the brains of rats and feeding these electrodes as a direct input to the LINC computer. (This computer, jointly developed by AFCRL and MIT's Lincoln Laboratory, is being used widely all over the country for studies in neurophysiology under the sponsorship of the National Institutes of Health.) A variety of programs have been written and checked out for this computer. One of these was used to investigate the closeness of fit of a mathematical model to data recorded from single nerve cells in the cochlear nucleus of cats.

VISUAL CORTEX OF CATS: In a related effort, under AFCRL sponsorship, researchers of the Harvard Medical School and the Massachusetts General Hospital, used the cat as an experimental animal. In this work, the animal's head was held rigid and its eyes forced open. A computer-driven digital display scope was used to present patterns of illuminated spots to the animal's fixed gaze. A PDP-4 computer was used to compile a record of single nerve cell firings in the cat's visual cortex resulting from the stimulus. The computer also compiled averages of evoked responses from larger electrodes touching the cortical surface at almost the same location.

By this means the time response to winking spots (on for 0.2 seconds, off for 1.8 seconds) was studied in detail, as well as the spatial organization of the visual receptive fields of individual nerve cells. Data from over a million individual stimulus presentations to more than 20 cats were thus processed. The sensitive signal-processing schemes used detected changes in cell firing patterns which a human experimenter could not perceive by looking at oscilloscope displays of the raw data itself.

Preliminary analysis of results suggests that there is a wide functional variety of visual cortex neurons. Typical of most of them is an inner, roughly circular, 'on' (or 'off') receptive field which is surrounded by an outer, eccentrically positioned, and often quite irregularly shaped, 'off' (or 'on') receptive field. The outer field is antagonistic to the inner one. Its effective size is inversely a function of the amount of background illumination. Since such eccentric arrangements in most cases define an axis of symmetry, the fine structure thus disclosed is consistent with observations made by others that cells at the cortical level are particularly sensitive to straight bars of light, or edge-segments, oriented at particular angles and moving in preferred directions in the visual field.

SPEECH AND VISUAL INFORMATION

Speech research at AFCRL has two parts: the first is concerned with anatomical, physical and psychological mechanisms involved in speech generation and perception — that is, with the operation of the vocal tract and with meanings which the listener assigns to words on the basis of their intonation. The second aspect is concerned with the processing of speech signals to reduce the amount of bandwidth needed for their transmission.

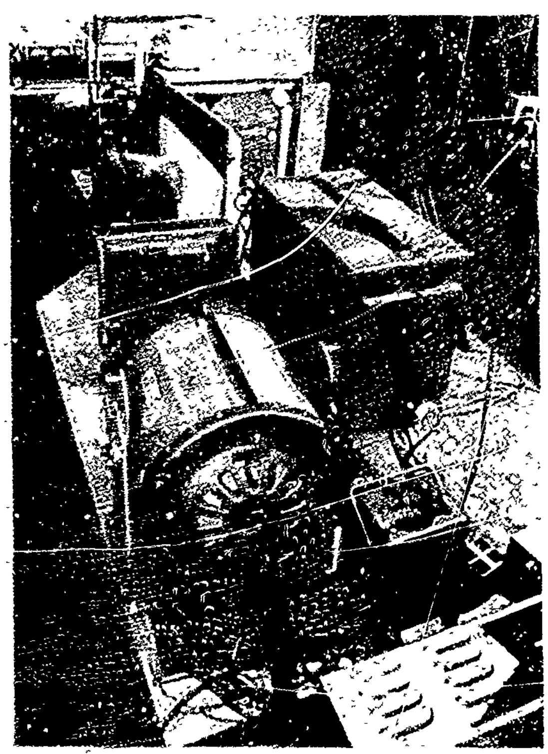
Visual information research is focused on television transmission and is also concerned with the transmission of the maximum information content over the narrowest possible bandwidth taking advantage of certain properties of the human visual system. Thus, it also takes the researcher into the area of human perception — into studies of the averaging, storing and interpolating properties of the human visual system.

From the standpoint of Air Force relevance, speech and visual research may lead to technologies for transmitting more information over greater distances with minimum amounts of power. (If the bandwidth needed to transmit information is reduced, power requirements are correspondingly reduced.) Narrow-band transmissions also provide more communication channels. Last, the work is germane to Air

Force security systems. If the signal is processed, it can then be more readily encoded.

VOICING: Speech is produced by exciting the vocal tract with one or more sources of acoustic energy. The activity of the vocal cords produces a "voicing" function which excites the vocal tract at the glottis. Noise generated by turbulent air flow at constrictions can also excite the vocal tract. The vocal tract acts as an acoustical filter.

The position of the tongue, lips, jaw, and velum can alter the transfer function of this filter and the acoustical properties of phonetic elements are in part determined by their configuration. Voicing provides talker identification and conveys the emotional content of the speech signal. Talker identity and emotional content are degraded in highly processed speech communication systems. By studying the voicing process, AFCRL hopes to identify the key attributes that may be extracted from the voice signal for transmission.



Laboratory equipments for making high-speed color motion pictures of the vocal cords are seen. Camera is at top center of picture. Of special interest are the high-intensity light source and the heat-filtering shield. Without filtering, heat from the light would harm the vocal cords.

Laboratory instrumentation consists of equipment for making high-speed motion pictures of the vocal cords, computer interface equipment for reducing and processing the data, and specialized programs for the computer. A recent addition to the program is equipment for supplying various gas mixtures to the vocal tract of a talker. The artificial atmosphere introduced in high-altitude aircraft and in space craft can alter the quality of the human voice.

Hitherto unobserved voicing conditions have been photographed by high-speed cameras. The start and stop of phonation has been photographed. Measurements show the vocal cord closing time is about 100 msec, while the opening time is about 60 msec. It has been observed that the initial motion of the vocal cords is always *inward* which shows that the Bernoulli effect (which has to do with pressures and fluid flow along a streamlined body and with the conservation of energy) is responsible for the initiation of vibration. The generally accepted theory of phonation, the myo-elastic aerodynamic theory, as presently formulated states that the Bernoulli effect can not adduct the vocal cords at the start of phonation. These experiments demonstrate that the Bernoulli effects can be more important than has been hitherto thought.

Computer programs for reducing and processing the vocal cord data on high-speed films have been developed and improved. A program has been written to convert the glottal area as a function of time to the volume velocity of the air flowing through the glottis. This volume velocity function is being compared with the function obtained at other laboratories by means of 'inverse filtering' and it can be used to excite a fixed vocal tract analog so that the result may be compared with the original acoustical signal recorded at the time the pictures were taken.

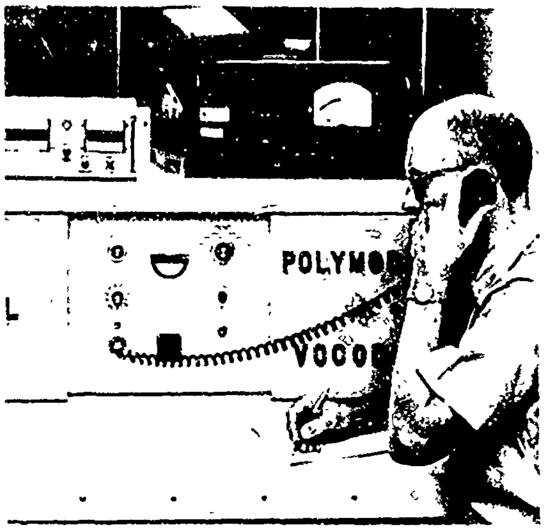
Measurements are also being taken on the voicing periodicity when gases other than air are used for talking. This led to a suggested instrumentation for improving the intelligibility of the speech of divers breathing gases other than air. Helium-rich mixtures are of special interest. As the amount of helium is increased, the speech sounds more and more high-pitched, due to the shifts in formant frequencies caused by the increased velocity of sound in the mixture.

SPEECH PERCEPTION: Intonation is the variation of voicing frequency with time. It is the 'melody' of the speech. The role that intonation plays in the perception of speech is not known precisely. Research in the Data Sciences Laboratory attempts to shed light on the question. Experiments carried out in the reporting period have indicated a strong influence of the linguistic content of an utterance on the way voicing is perceived by a listener. Other experiments explored whether or not simple transformations of the intonation would change the emotional content of a speech signal. Several years ago a set of utterances was recorded in which several semantically neutral sentences were read with eight different emotions. In a forced-choice situation listeners could identify the intended emotion correctly about 90 percent of the time. If only the timing of the pitch pulses and their amplitudes are retained, identification is about half of what it is for the complete signal.

Recently these pitch contour signals were processed on the computer to change the mean value of the pitch frequency and the variations about the mean. The traditional explanation of how pitch conveys emotion is that the pitch is transformed upwards or downwards, expanded or compressed, and so on. All of these transformations were synthesized in this experiment. None had an effect on the emotional connotation of the speech as interpreted by listeners, and it is therefore evident that the traditional explanation is not adequate. A more relevant model is presently under investigation.

Another aspect of intonation is its linguistic function. The rise and fall of the pitch frequency, together with the break points in the intonation contour, furnish to the listener acoustic cues on how to segment the speech signal into blocks of speech that constitute useful inputs to his syntactic recognition process. In addition, intonation can impart different meanings to utterances that contain the same words by grouping the words into different blocks which direct the listener's recognition routine.

SPEECH COMPRESSION RESEARCH: Vocoders are equipments which process speech signals and extract relevant components of the signals for transmission in digital form. This implies that redundant and non-essential aspects of the signal are eliminated, thus reducing the amount of bandwidth needed to



The polymodal vocoder is a speech compression device capable of bit rates from 1200 to 9600 bits per second. The equipment includes a speech analyzer that can adapt to different voice characteristics, and a new speech synthesizer producing an unmatched natural voice quality.

carry the signal. Vocoders dominate the field of speech compression research. In spite of the great amount of research on these equipments over the past decade, their full capabilities have not yet been realized. Speech compression research at AFCRL is focused on improving these capabilities.

The intelligibility performance of channel vocoders of current design is typically better than 90 percent word intelligibility with 2400 bit-per-second systems. With the achievement of this level of speech intelligibility, program emphasis is now directed to problems of vocoder quality and naturalness and of attaining a higher degree of compression.

NEW VOICE SYNTHESIZERS: Processed speech signals must, of course, be reconstructed at the receiving terminal by associated vocoder equipments. Following this demodulation process the voice is reconstituted by means of a speech synthesizer. During the reporting period a new method for speech synthesis was originated at AFCRL which provides significant improvements in the quality and naturalness of vocoder speech. This synthesizer has had immediate and wide acceptance by many agencies concerned with voice communications. AFCRL was also asked to evaluate the use of the synthesizer for Syncom transmissions. The new technique is applicable to the design of a variety of speech synthesis devices. The key feature is the use of function generators to simulate the waveforms that occur during the human production of speech.

While it has been recognized that pitch-synchronous modulations of the frequencies, bandwidths, and phases of the vocal oscillations occur commonly in human speech, speech synthesis devices have generally ignored these effects. It was hypothesized that these second-order modulations may occur in human speech with sufficient generality to constitute significant correlates of natural voice quality. Consequently, a speech synthesizer capable of imposing these modulations on synthetic speech should sound more natural. This is the basis of the new synthesizer.

The new synthesizer device has been named a "vocal response synthesizer" because it synthesizes the response waveforms of the human vocal tract. The experimental model was designed to operate with an 18-channel vocoder system. The magnitudes and phases of the second-order modulations are adjustable to permit study of their effects on speech quality and naturalness, and their role in governing the unique voice quality characteristics of different individuals. A further refinement lies in controlling these parameters from speech analysis data with the use of narrow-band intonation signals in order to model very closely the voice qualities of individual talkers.

The function generators of the synthesizer avoid the necessity for band-pass filters in the vocoder design. This means that the new speech synthesizer also offers reduction in size, weight, and cost. Another benefit lies in the fact that the output speech inherently contains the fundamental pitch of the voice, a significant advantage if vocoder systems are to be operated in conference communications. Such communications often require tandem operation where the output on one vocoder is used as an input to another.

The new synthesizer has demonstrated 94 percent word intelligibility with one pass through the vocoder, 90 percent after the speech signal goes through the same vocoder a second time, and 78 percent with a third pass through the vocoder. By contrast, conventional vocoders are unable to detect the pitch of the voice after one pass through a vocoder system, and are therefore incapable of satisfactory operation when connected in tandem.

The new synthesizer was incorporated in an experimental multimode vocoder delivered in the spring of 1965. The improved vocoder system will be used as the input/output processor for studies of pattern-making techniques to permit operation of the vocoder as a 600 bit-per-second voice communications device.

Two models of the AFCRL experimental multimode vocoder in use for some time were modified to incorporate the new speech synthesis technique. These modifications make available three high performance vocoder systems to study the conference communications problem — three systems being the minimum number as needed to simulate and study a conference communications network. All three experimental multimode vocoders include conventional vocoder configurations and voice-excited vocoder configurations in addition to the new synthesizers.

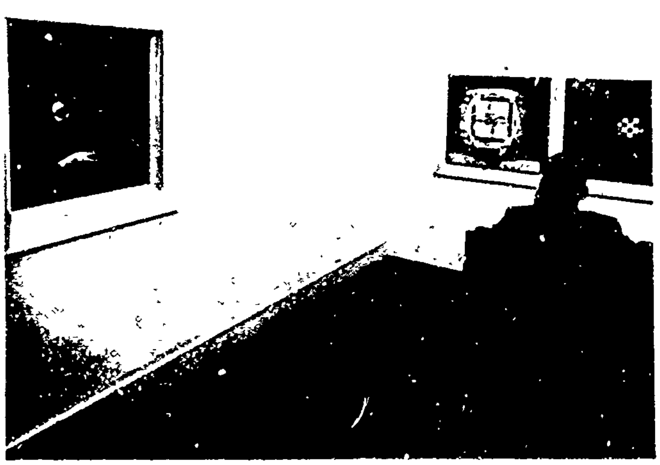
NARROW-BAND TV DISPLAYS: Techniques for transmitting black-and-white television pictures with drastically reduced bandwidth compared to conventional television are being studied. Reductions to about 160 kcps are believed possible. This compares with a bandwidth of four Mcps for commercial television. The technique depends upon the integrative properties of the human visual system.

It was demonstrated that reduced bandwidth pictures can be achieved by using a pseudo-random scan technique and slower transmission rates. This can be accomplished with no picture degradation provided the bandwidth reduction factor is not too large (perhaps up to 25). At rates below this, a useful moving picture can be transmitted, but quality deteriorates as the rate is decreased. A major portion of the program is devoted to quantitative measurements of the factors involved.

A picture-testing facility (a viewing room in which test subjects give subjective evaluations of picture quality) has been established. Here various types of scans are generated under conditions of controlled brightness, contrast, resolution, and rate. Flicker fusion, motion resolution, effects of phosphor persistence, grey level fusion, and figure detection in pictures of drastically reduced point writing rate are studied.

To illustrate the kinds of experiments

TV picture quality is evaluated both by computer and by test subjects. In upper photo the results of computer analysis are displayed with a first-order brightness distribution shown on scope. But quality is ultimately a subjective value. In lower photo, picture degradation resulting from transmissions over narrow bandwidths is evaluated by a test subject.



conducted with this facility, one study involved measurements of thresholds of perception. Using a pseudo-random scan, a uniform field containing a dark rectangle in motion is presented. Frame periods (the time taken to write all points in the picture raster) were varied from 1/60 second to six seconds. The object is to see the rectangle. If the contrast between the rectangle and the background is low, a fairly high point rate is required for perception. However, as the contrast is increased, the rate may be decreased to achieve the same perception probability, until in the extreme of black or white the rectangle can still be perceived at a six second frame rate and using exposure times of perhaps only one second. This means the subject does not even have to see all the points in the picture.

It appears from this result that the boundary of the rectangle is perceived owing to the contrast between the interior and exterior rather than by seeing a sharp boundary between interior and exterior. This supports the contention that the human visual system integrates light in both space and time and that short integration times or marginally different objective contrasts result in a *gradual* decrease of subjective contrast.

Efforts such as these have direct relevance to the interpretation of surveillance data. Explorations of specific situations related to surveillance problems will be given heavy emphasis in forthcoming phases of the work.

Among the equipments used by AFCRL in this research are a video magnetic tape recorder and television cameras. Capability also exists for duplicating picture tapes, and for generating high quality pictures from a noisy input by integration in a storage tube. The investigations make extensive use of a small-scale, high-speed computer (PDP-1), and peripheral equipments.

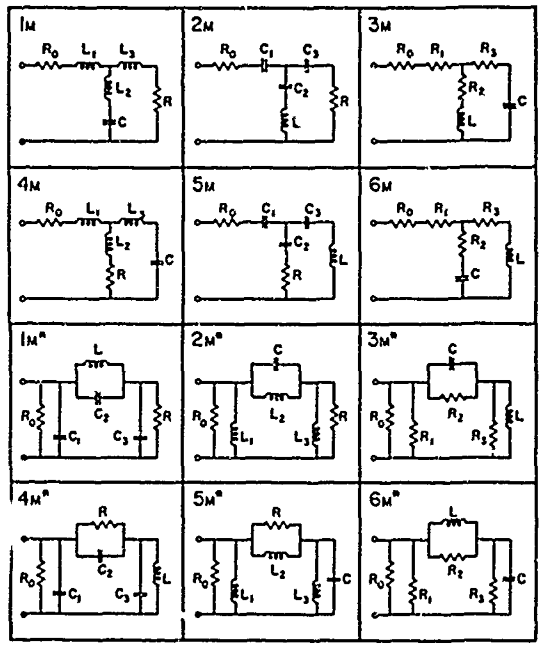
NETWORKS, CIRCUITS AND THEORY

The work reviewed in this section consists of several studies concerned with computer organization and structure. One goal of this work is to determine theoretically optimum internal organization. But theoretically optimum networks and circuits which can be realized in manufacture are not necessarily the same. The Laboratory is concerned both with the theoretical and the realizable aspects of the problem.

NETWORKS AND CIRCUITS: The goal of network theory is more economical designs — that is to say, circuits that occupy less space and weigh less. The design of networks with prescribed behavior has made great strides since the formation of modern (as against classical) network theory in the early 1940's. Modern network theory requires that the circuit designer have a profound knowledge of applied mathematics. Emphasis at AFCRL has centered on computational methods that permit efficient solutions of mathematical problems occurring in network theory. Frequently these solutions illuminate other areas of applied mathematics.

This work resulted, during the reporting period, in one major contribution to the field of applied mathematics and another one to the field of circuit theory. A new technique has been developed and completed for finding the roots of algebraic (polynomial) equations up to the order 15. The root-finding problem is a very common one in modern network design. The new method has been elaborated for the use of a desk calculating machine, the primary tool in network research.

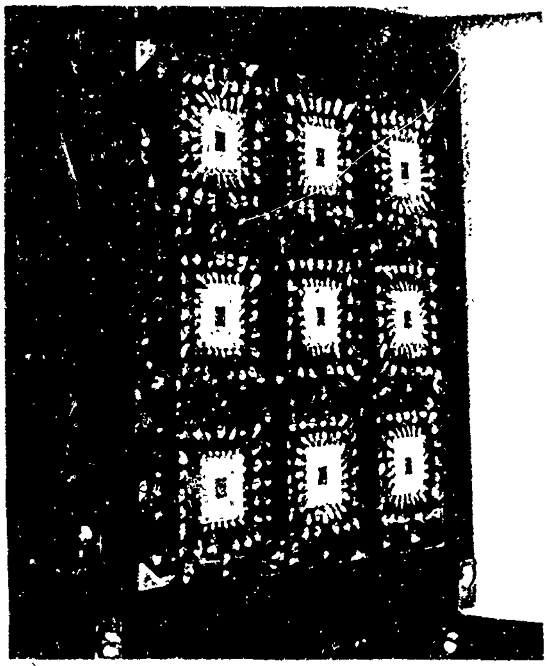
The network theory contribution is concerned with the generalization of



An electronic circuit to perform a particular function can assume many configurations. Network and circuit theory is concerned with developing the simplest and most reliable circuit — and one that can be realized in manufacture — for a particular function.

the so-called Brune section. A method has been developed to treat the Brune section as a special case of the general "Perfectly Coupled and Shunt-Augmented T." It is expected that this general T will greatly simplify fabrication procedures with respect to analog networks.

LOGIC NETWORK ANALYSIS: Computer networks in the past were made up of a small set of basic elements, each of which performed a single specific function. From these basic building blocks more complex nets were — and are — constructed. Once such a net is designed, however, its function cannot be changed. AFCRL is examining nets that may be able to perform many functions. Such nets are called polyfunctional.



Experimental model of an eight-neighbor, uniform modifiable logic network is shown above. The dark squares in the center of the white ceramic wafer each contain 16 transistors. To design such nets, and to experiment with them, however, it is desirable to construct the circuit using larger standard components which are easier to work with. Such a unit is shown in the lower photograph.

To use polyfunctional networks, two basic questions must be answered: 1) Given an arbitrarily large net, what is its overall function set under all possible sets of function assignments to the individual elements? and 2) What happens to the overall set of functions if the net is composed of unreliable components? — a basic concern in the real-life situation where total element reliability is unattainable. An AFCRL paper, published in *IEEE Transactions on Electronic Computers*, reporting on the work covered in this section on Logic Networks received special recognition as one of the three most significant papers published by an AFCRL scientist during 1964.

In last year's report, considerable work was reported on iterated homogeneous nets. These are nets which result from an initial array of elements having the same number of inputs and outputs as the individual element. Each element is replaced by a replica of the whole array and sets of this array are in turn replaced by a larger array, a process of iteration that can be repeated any number of times. Such nets "oscillate" upon iteration. This means that at a given stage in the iterative growth process the net produces a certain set of functions. Further iteration produces a different set. After a certain number of iterations (the "period") the sequence repeats itself. A net with period "one," that reproduces the same function set every time, is said to converge.

Two major problems in the theory of homogeneous polyfunctional nets are under study:

1) Given a homogeneous net and an initial function assignment to each of the elements of the net, what is the oscillation period of the net? When is

this period unity? Or, stated another way, when does the net converge?

2) If each element of a homogeneous net is probabilistic, what is the probability that the net performs some prescribed function at a later iteration? Under what conditions does the net perform a particular function with probability greater than that with which the individual element performs this function?

Many new results were obtained on the first of these two problems, e.g., it has been found that for every net which converges there exists a larger net which also converges. For every number of inputs m greater than 1 there exists a net with m inputs and one output which does not converge.

Many theorems were proved concerning special classes of nets which enable the designer to decide with a minimum of effort whether or not a net with particular initial function assignment converges.

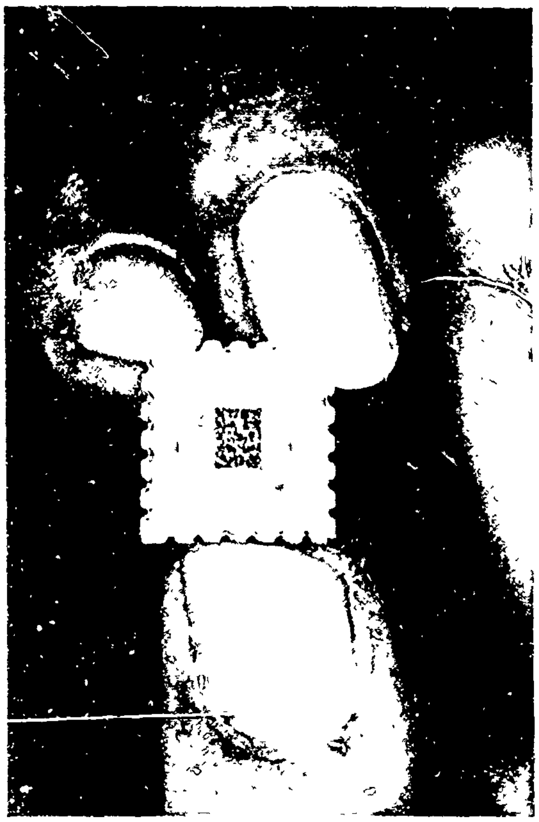
Perhaps the most comprehensive result to date has been a theorem that reduces the problems of testing convergence of all 65,536 sets of initial function assignments for the so-called 2 x 1 bordered net to only eight subsets. If the net converges for these eight subsets then it converges for all subsets. Convergence has been found to be a consistent property of nets with regular structure. This has been proved for triangular nets and pyramidal nets. A more general statement is now being sought.

Curiously, genetics — in particular genetic dominance — has been found to have an analogue in network problems. Three theorems have been proved in this area which establish: 1) in m x 1 bordered nets the majority functions dominate the class of functions D^1 (functions whose canonical form contain $x_1 x_2 \ldots x_n$ but not $\bar{x}_1 \bar{x}_2 \ldots \bar{x}_n$), 2) the product function with all variables present dominates the class of all product functions, and 3) the sum function with all variables present dominates the class of all sum functions. A set of functions is said to dominate a class of functions with respect to a net if the net reproduces a member of the set of functions with arbitrary reliability.

FABRICATING UNIFORM MODIFIABLE LOGIC STRUCTURES: The theoretical studies discussed in the preceding paragraphs would represent nothing more than an interesting exercise in logic and mathematics if they could not be realized in manufacture. The present state-of-the-art in microcircuit techniques now makes it possible to realize these complex structures. Structural complexity is no longer an economic or physical limiting factor. The separate advances in fabrication techniques and logic networks, when combined, could well bring about a new species of data processors. Designers can now think in terms of machine organization using large numbers of identical elements fabricated as a single unit.

Schemes of organization in which most of a data processor may be made of physically identical cells incorporated into a uniformly structured array are possible. Some of the more interesting forms have already been fabricated. The cells or elements used in these uniform structures may vary in complexity from only a few active devices performing simple logic functions, to several hundred devices having the capabilities of a simple computer.

Two applications of uniform logic networks have been considered. One is a uniform network for realizing sequential and combinatorial logic networks which uses the NOR function as the



Judged against the state-of-the-art of just one decade ago, a revolution has come to electronic circuity. Through its in-house work and through judicious selection of a substantial number of contractors in the mid-1950's, AFCRL gave impetus to this revolution.

basic element. The other application is for a more specialized function, namely, pattern classification. AFCRL studies have concentrated upon the eight neighbor uniform modifiable logic network. This is a network suited for sequential and combinatorial functions. It can be represented by the vertices and arcs of the regular infinite graph of degree eight illustrated on this page. The state and function of cells of this network can be associated with the vertices of the graph and the interconnection of the cells with the arcs between the vertices. Thus the possible structures of the network can be represented as all the directed graphs which are obtained from the basic eight neighbor graph by deleting arcs. A mathematical model of this network has been obtained and programmed on the AFCRL computer so that the sequential behavior of networks with up to 25 vertices can be studied by computer simulation.

Various types of sequential networks having standard behavior have been designed. These networks can be simulated by computer, and also tested on a modifiable logic network model which has its interconnections controlled by a light pattern derived from IBM cards. These cards can be generated by computer. This unit was designed and fabricated in-house.

Under AFCRL contract a metal oxide semiconductor field effect transistor has been developed possessing many characteristics that make it suitable for use in digital logic networks. Among these characteristics is a very high input impedance. The fabrication process has fewer steps which should lower the rejection rate. Several wafers containing sixteen field effect transistors on each and connected to perform the logic of the modifiable eight neighbor NOR network were assembled and tested during the reporting period. Although these particular elements displayed instabilities in their characteristics it is evident that many of the logic functions theoretically possible can be realized in manufacture. Networks under fabrication at the conclusion of the reporting period are expected to be greatly improved.

Techniques are also being developed for controlling effective interconnection of elements by light. The sensing elements used in this technique are of the same size as the MOS transistors.

For several years AFCRL has supported work under contract dealing with magnetic domain-wall interaction in ferromagnetic thin films. This work has resulted in several new device concepts which may allow the use of thin magnetic film devices for digital logic networks. In particular, it may be possible to put magnetic film NOR elements together in eight neighbor networks similar to those already fabricated using semiconductors. This possibility will be explored further in the coming year.

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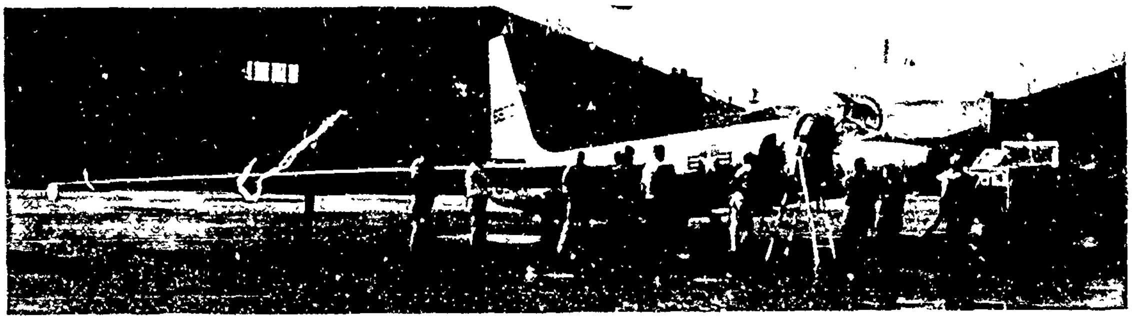
AFCRL's Meteorology Laboratory conducts research into the causes of weather and how to predict and modify it. Thus the Laboratory must deal with many area scales of meteorological activity, ranging from thousands of miles to a few feet, and with processes from ground level out to 70 or 80 miles. A thorough understanding of all atmospheric parameters and their complex interrelationships is the requisite first step toward precise weather prediction — and ultimately toward modification.

Meteorology is primarily an observational rather than an experimental science. To observe weather processes throughout the tremendous volume of the earth's atmosphere, AFCRL meteorologists during the reporting period made notable progress in improving observational techniques and in developing new instrumentation. The design of advanced meteorological instrumentation, however, was only one phase of a much larger program encompassing observation, analysis and theory.

The Laboratory's large, diversified program, its multiplicity of advanced facilities and sensors, and, foremost, its large staff of world-recognized meteorologists, combine to provide the Air Force with a unique capability in a research field which has, historically, been of prime importance to Air Force operations. Through an intimate association with the Air Weather Service, with the U. S. Weather Bureau, and with professional societies which have AFCRL membership on their governing bodies, the Laboratory has estab-



A U-2 aircraft used for meteorological observations is being readied for a flight at Hanscom Field, Mass. An instrument pod in the lower part of the fuselage contains cameras, navigational equipment, and a number of extremely sensitive and accurate probes.

lished a broad bridge between the research community and Air Force operational commands. For this reason, the Laboratory is frequently called upon by the Air Force to investigate problems in urgent demand of solution.

AIRCRAFT AND SATELLITE INSTRUMENTATION

Most meteorological processes, because of their large scale, cannot be duplicated in the Laboratory. Observations must be made and data collected over far-flung regions and at many altitude regimes. Aircraft have, therefore, become indispensable test beds in almost every area of meteorological research. They can carry a large variety of probes into and above weather systems, and they take the researcher with a minimum of logistics difficulty to widely separated geographical areas for observations. Much of the research discussed throughout this chapter would not have been possible without aircraft capability. The Meteorology Laboratory operates two highly instrumented aircraft, a U-2 and a C-130A. Other Air Force elements supply additional aircraft when needed.

Satellite (optical and infrared) measurements provide new types of information needed to improve forecasting, particularly information about weather conditions in areas where no observations are made on a regular basis. But the utility of meteorological satellite data has yet to be fully exploited. The major problem is that of data reduction. To be useful, the data must be reduced to numerical form suitable for input into a computer program. AFCRL's satellite meteorology program is concentrating primarily on this problem.

THE U-2 METEOROLOGICAL AIRCRAFT: During this reporting period, an instrumented U-2 has helped AFCRL meteorologists hunt down the cause of radar tracking errors at Cape Kennedy due to atmospheric refraction, supplemented balloon sampling of atmospheric ozone, and taken pictures of thunderheads and measured their electric fields. It was flown to Florida on 14 October 1964, to investigate hurricane Isbell, taking wind, temperature and infrared measurements as well as photographs. It has also been used to flight-test new and improved instrumentation and to help calibrate infrared sensors aboard satellites.

To make best use of the data collected

by the U-2, its position and velocity at the time it collects a given set of data must be known with great accuracy. During this reporting period, two navigational devices, which greatly improve this accuracy, were installed. One device is a new APN-153(v) Doppler system which provides an automatic means of determining the plane's geographical location and computing wind velocity. The second device, an electronic altimeter which measures the distance from the aircraft to the terrain below, was placed in the instrument pod.

Several new sensors were also added to the pod, which is mounted inside the U-2's belly between the wings and the cockpit. These included improved electric field meters, another infrared radiometer (to supplement the one already in the pod), and a small-turbulence recorder. Less accurate vortex and reverse-flow thermometers were removed from the pod. A fast-response Rosemont temperature probe was retained and a second one is to be added. A 16mm time-lapse camera, to supplement the 70mm tracker camera and increase the plane's cloud-study capability, will also be added in 1965.

The Laboratory's C-130 aircraft is instrumented for cloud probing. Externally mounted sensors include temperature probes, electric field meters, and a refractive index measuring device. The aircraft also carries cameras for photographing clouds.

THE C-130A FLYING LABORATORY: A C-130A aircraft is instrumented for cloud physics research. Operating at altitudes up to 35,000 feet, it carries devices for sampling the liquid water content of the atmosphere, including that in supercooled clouds (clouds composed of liquid water droplets at temperatures below freezing), and for measuring atmospheric humidity. It also has various temperature probes, electric field meters, and ducts for sampling atmospheric refractive index at microwave frequencies. Most of this instrumentation is mounted externally. In addition, the aircraft carries three cameras for mapping terrain and cloud cover horizon-to-horizon, and four 16mm time-lapse cameras which take one frame every three seconds and are used to record the growth of clouds.

During this reporting period, the C130A (together with the U-2) took part in refractive index measurements at Cape Kennedy and in many other studies in cloud physics.

SATELLITE METEOROLOGY: During the past year and a half, the AFCRL satellite program has been in a state of transition. Its initial objective was the development of basic techniques for rapid reduction of weather satellite data. Now that such techniques have been demonstrated to be feasible, preparations are being made for the next phase. This is the incorporation of satellite data into the Air Force's automatic global weather analysis and forecasting system.

AFCRL's previous Progress Report discussed a system developed under contract which automatically, and on a real-time basis, removes distortion from a satellite picture, adjusts it to fit a predetermined geographic grid, and assembles a series of successive pictures into a continuous strip. Early in this reporting period, the contractor demonstrated this system to the military, NASA, and the U. S. Weather Bureau. One outcome of the demonstration was that NASA has funded the development of a compact operational system.

The focus of in-house attention was the evaluation of the Automatic Picture Transmission (APT) systems aboard the TIROS VIII and NIMBUS A meteorological satellites. Receiving equipment was installed at AFCRL. The quality of pictures from the latter satellite was outstanding, bringing satellite meteorology much closer to the operational stage.

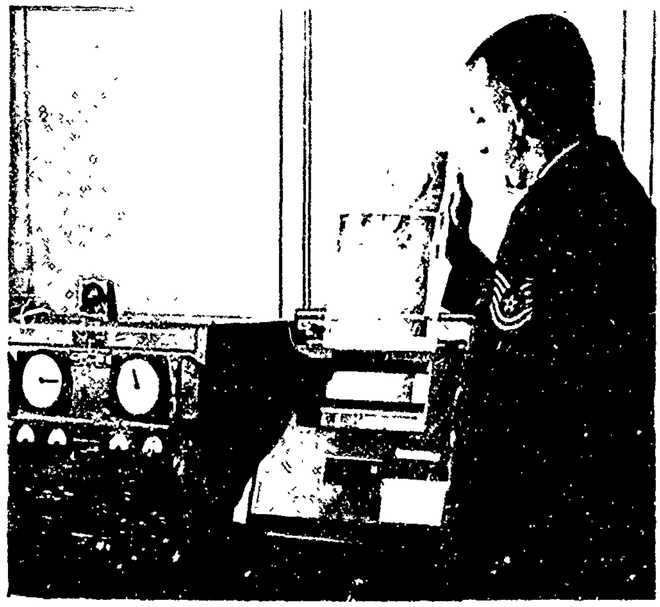
WEATHER SATELLITE VIDEO CALIBRATION: In line with the above objective, AFCRL scientists combined several studies by both contractors and in-house researchers to the correction of TIROS video system errors. The problem was to determine if the albedo (brightness of reflected light from a surface) can be accurately computed from the satellite photographs. One contractor made detailed statistical studies to determine corrections for the lens-vidicon-CRT system used to photograph and record satellite pictures. One of the most productive calibration techniques involved simultaneous photography of the same cloud systems by a U-2 and a weather satellite.

Analysis of these data showed good agreement between the albedo computed from U-2 and from satellite photographs. The albedo was generally within the range of theoretical values except for the albedo of thick clouds associated with cyclonic storms which was about 10-20 percent greater than expected. Whether this departure from theory happened because of unforeseen calibration errors, or if not, whether it has any meteorological significance, is yet to be determined. This kind of analysis is fundamental to the automatic identification of cloud types from satellite data, a capability that will greatly increase the amount and quality of information available through a satellite global forecasting system.

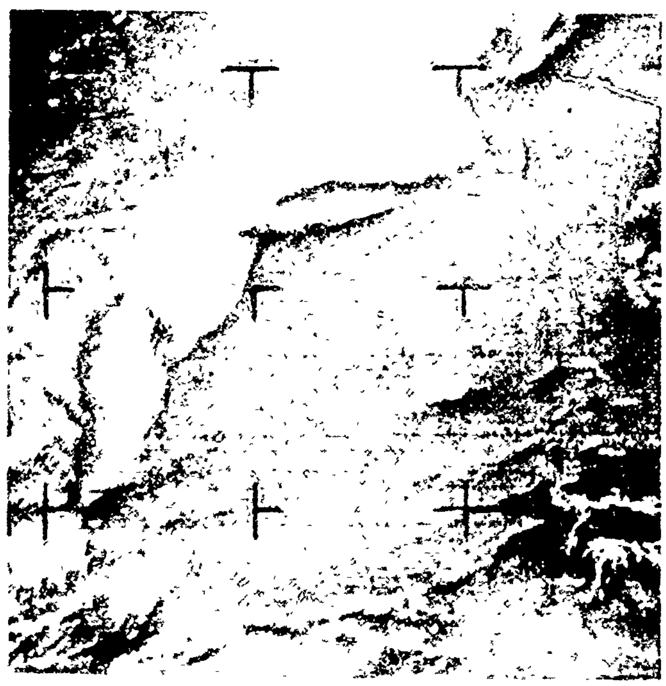
SATELLITE INFRARED SENSORS: Studies of infrared sensors for measuring temperature and other physical characteristics of clouds have been conducted for several years. Infrared sensing is the only means now available for satellite observations of nighttime cloud cover. Satellite-borne infrared radiometers also hold promise as a means for measuring temperatures in parts of the world where routine observations are not made, or which may be politically inaccessible.

A new infrared radiometer was developed, tested, and calibrated during the period. This radiometer was checked out in the U-2 during flights over cirrus shields, severe storms, and Hurricane Ginny in 1963. One of the more interesting results of these flights was the discovery that the radiometer "sees" into cirrostratus and other stratiform clouds. On the average, the observed temperature is representative of that in the top 5,000 feet of the cloud. This fact, which indicates that the physical characteristics of cloud cover must be considered when converting radiometer measurements to temperatures, has an important bearing on the establishment of automatic procedures for analyzing infrared data from satellites.

The contractor who built the equipment for automatically rectifying and mosaicking satellite photographs for AFCRL (see above) has also demonstrated the feasibility of preparing pictorial representations of the TIROS infrared radiation data.



Between December 1963 and June 1964, the period in which the APT system of TIROS VIII was active, AFCRL's receiving equipment shown above recorded hundreds of pictures transmitted directly from the satellite. Cape Cod, Long Island and Chesapeake Bay are clearly delineated in one such picture shown below.



WEATHER RADAR TECHNIQUES

During the period covered in the previous AFCRL report, weather radar research at AFCRL was marked by a heavy emphasis on techniques for automatically processing weather radar data. Evolving from this earlier work was the STRADAP (Storm Radar Data Processor) system, which automatically plots horizontal cross sections of storm top and storm intensity at discrete altitude levels within cloud systems. While this work on automatic systems continues, the present reporting period is marked by the discovery or application of new weather radar techniques. This section will deal with these radar developments rather than with weather research in which radars are used as sensors.

RADAR WIND VELOCITY MEASUREMENT TECHIQUE: A new radar technique for measuring wind velocities in cloud systems was developed. The technique is applicable to conventional radar equipment after only slight modification of the antenna, thus providing a wind measuring capability to radars which could previously observe only storm patterns. The method provides a "pseudo"-Doppler capability without the complexity and cost of a conventional Doppler radar.

The technique is one using two beams squinted slightly to either side of the antenna bore sight axis. The bore sight axis is directed perpendicular to the direction of the wind. Precipitation echoes in the right beam produce a small positive Doppler frequency shift proportional to the upwind component while those in the left beam produce an equal and opposite Doppler shift. Since the radar is incoherent, neither Doppler component can be measured. But since the echoes from both beams arrive at the common receiver synchronously, they beat with one another to produce a fluctuating echo whose amplitude fluctuates with a frequency which is twice the Doppler frequency. Thus the fluctuation is a unique measure of the cross-wind. (This may be recognized as a version of the Janus-type Doppler navigator.)

When the system is described in greater detail, it is found to be more complex. Because of the finite width of each beam, each will produce a spectrum of Doppler frequencies proportional to the beam width. Moreover, the spectrum will be broadened by contaminating effects such as turbulence and wind shear. As a result, the beating of the echoes from the two beams will produce not a single fluctuation frequency, but a spectrum of such frequencies. When the spectrum is analyzed, we find that it has a well-defined peak at the frequency corresponding to the thin beam case. Fortunately, it is not necessary to analyze the entire spectrum but only to measure its root mean square (RMS) frequency. The difference between the RMS fluctuation frequency on the two beams from that on either one of the beams is then a unique measure of the wind speed and is independent of both the beam width and the contaminating influences.

The beams cannot be separated too greatly; otherwise a storm of limited extent may not occupy both beams simultaneously. Since the upwind and downwind Doppler components are therefore small, the accuracy of the method decreases with low wind speeds. However, it is particularly well suited to the measurement of hurricane winds and has been recommended to the Air Weather Service for their use in hurricane reconnaissance. AFCRL is now assembling equipment to test the method.

When used on a Doppler radar with a third axial beam, the axial beam would measure the wind component along its axis, while the two squinted beams would measure the perpendicular component. In this way, the complete wind vector can be measured at each and every point in space.

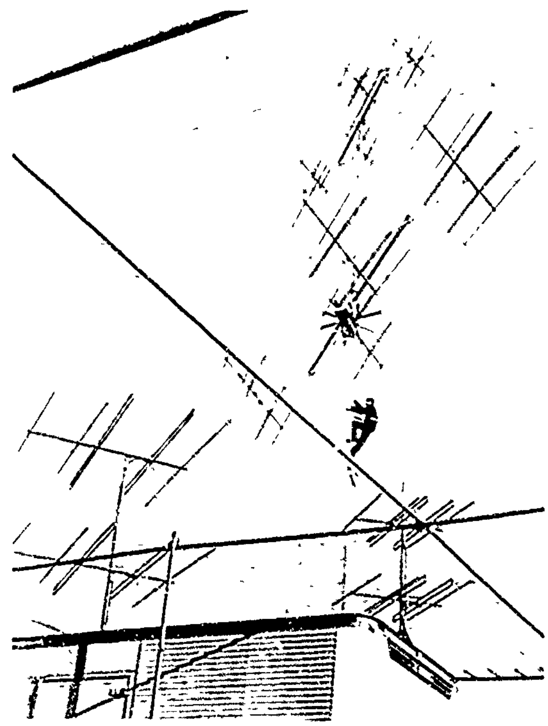
WIND AND DENSITY DATA FROM METEOR TRAILS: Most meteors burn up between 80 and 105 km above the earth due to deceleration in the earth's atmosphere. (A critical portion of the deceleration of reentering space vehicles occurs in this same layer.) Therefore, meteors can be used as natural tracers to tell much about atmospheric variability in this region. They provide a means for monitoring this region on a continuous basis.

Since June 1964, a unique radar located at AFCRL has been used to make observations of ionized meteor trails. Operating at frequencies of 36.8

and 73.6 Mcps, this equipment is being calibrated to derive upper atmosphere wind and density information based on the wind influences and dissipation of the ionized trail. (For discussion of another system developed to obtain similar information from meteor trails, see Chapter X).

Radar signals reflected from an ionized trail are processed to obtain the range, Doppler shift, elevation angle, and signal strength. The trail is imbedded in the atmosphere and moves with the wind. By assuming that vertical motions are negligible, one component of the horizontal wind velocity can be obtained from each trail observed. By rotating the antenna system 90°, the other horizontal wind component may be obtained from other trails to give the total horizontal wind velocity.

"Underdense" trails (those left by meteors of less than one millimeter in diameter) are used for density measurements. As one of these trails diffuses, the signal strength reflected from it decays exponentially. This rate of decay is proportional to the rate of diffusion of ionized particles which is in turn inversely proportional to atmospheric density. Thus, density can be determined from the rate of decay of the returning signals. Decay time for a meteor trail is on the order of a fraction of a second.

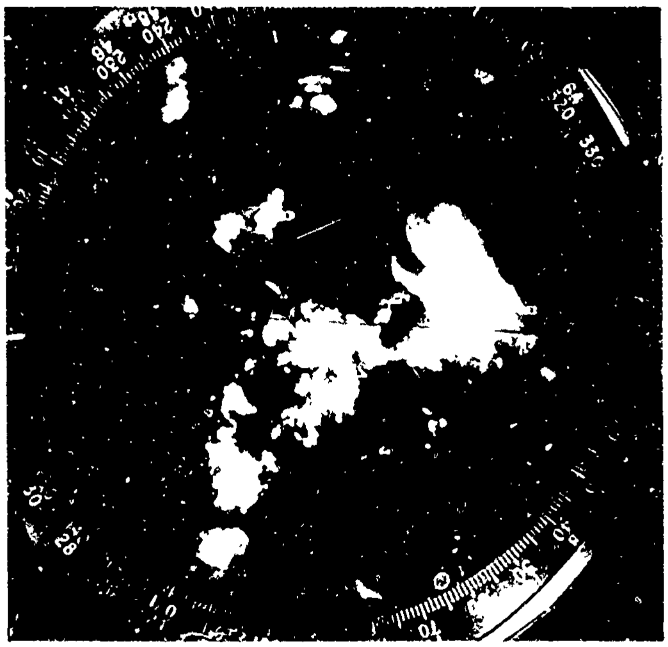


Radar pulses transmitted from this antenna are reflected from meteor trails to obtain wind and density information in the 70-100 km region. The meteor trail radar is located at AFCRL, Hanscom Field, Mass.

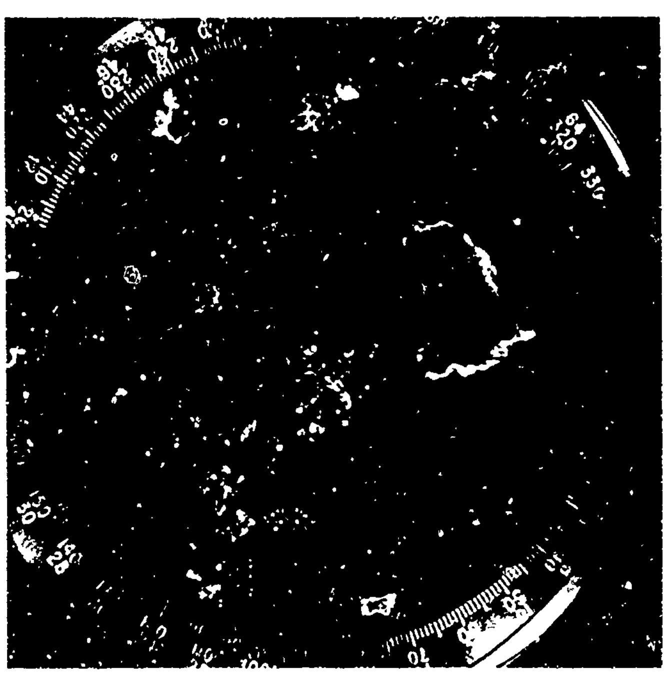
CORRECTING SIDELOBE ERRORS: Antenna sidelobes have been a basic antenna problem since the beginning of radar. These lobes on either side of the main antenna beam result in false directional or altitude information. For weather radars they pose a special difficulty because of large size and high reflectivity of cloud targets.

Although not much can be done about this problem from the standpoint of sidelobe suppression within the radar itself, Laboratory scientists have come up with a formula for correcting sidelobe errors. The formula resulted from an analysis of mathematical models of a thunderstorm's reflectivity structure and of a radar antenna's lobe pattern. Where sidelobe errors predominate, the correction formula is good up to the point where the product of range (in nautical miles) and half-power beamwidth (in degrees) nears 100.

MULTILEVEL RADAR CONTOUR MAPPER: During the period, AFCRL developed an extremely useful piece of auxiliary equipment for intensity quantizing, displaying, and photo-



The same thunderstorm is displayed in a normal video presentation (top) and in a contoured form (bottom) produced by AFCRL's new Video Data Processor. The contours represent different signal strengths in the returning echoes and provide a much more detailed picture of cloud activity.



graphically recording radar weather information. This instrument greatly increases data acquisition capability by quantizing weather radar echoes in the form of contours in 10 decibel steps and displaying these quantized echoes on each of two video screens (see illustration). This useful display allows the observer to interpret visually the intensity of weather radar echoes in terms of the quantized white, grey, or black levels.

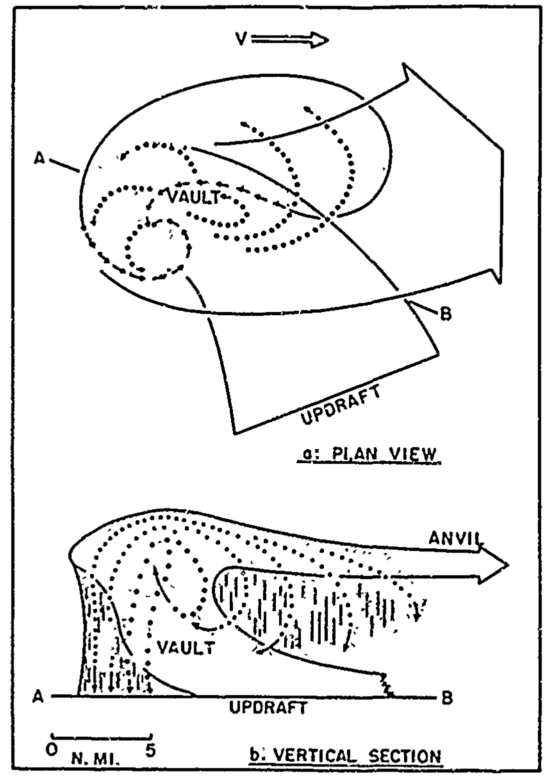
LARGE CONVECTIVE SYSTEMS

Clouds and their continuing varying patterns are universal indexes of weather. Beyond the generalized knowledge of growth, formation and dissipation, the dynamics of cloud systems is inordinately complex. The physics of clouds is a fundamental aspect of AFCRL's meteorology research program. Of the cloud types, convective clouds are of primary interest because of their huge energies, their more complex internal structure, and their destructive force. During this reporting period, most of AFCRL's work in cloud physics represented a continuation of earlier programs — observation of cloud patterns and growth, hurricanes, radar scattering from hailstones, and the study of thunderstorms.

CONVECTIVE CLOUD GROWTH: During this reporting period, AFCRL scientists completed two new studies designed to gain further insight into the growth of convective clouds. The first study, using time-lapse cloud photography, coordinated with aircraft observations inside the clouds, yielded relationships between the observed growth of active cumulus clouds, and their internal velocity and temperature fields. The results of this study were in good accord with those predicted by theory.

The second study was designed to study the processes which determine the life-cycle of a thunderhead. Photogrammetric measurements of anvil outflow from an isolated cumulonimbus made possible an estimation of how much of the cloud's available buoyant energy it dissipated by mixing with the surrounding air.

RADAR OBSERVATIONS OF THUNDERSTORMS: An investigation was made of the organization of convective structures that produce large hail and tornadoes. From this investigation, earlier models were extended. Based on echo returns from weather radars, it was shown that tornadoes are usually found beneath an echo-free vault which exists in the core of the storm and extends upward beneath the highest echo top. The vault is thought to be an indication of the most intense part of an organized, persistent updraft. The tornado hook, an echo frequently seen on radar under tornadic conditions, was demonstrated to be the horizontal cross-section view at low altitudes of the vault and its adjacent wall cloud. Evidence that vaults often precede the development of hook echoes and tornadoes offers some promise for eventual development of a tornado identification technique based on the structure of a thunderstorm radar echo.



Horizontal and vertical cross sections of a thunderstorm were drawn from radar echoes. The density of the small dots is proportional to the intensity of the echoes. The lines of larger dots represent precipitation in the form of hailstones. The vault is an area from which there are no radar echoes.

An airflow model previously developed by AFCRL scientists for persistent convective storms has been extended to fit the case of those severe and often tornadic storms which travel to the right of the tropospheric winds. An interesting feature of this model is the cyclonic turning of the updraft, which is believed to be responsible for the cyclonic motion observed in hook echoes.

Experiments performed by Swiss scientists under AFCRL contract have provided an important contribution to our knowledge of backscattering cross sections from "spongy" (homogeneous mixture of ice and water) ice spheres. The results contain the answer to a long-standing dilemma of unexplained reflectivity profiles observed in hailstorms. Meteorological interpretation of these results by AFCRL scientists shows that a concentration of only 3 g/m^3 of one-centimeter diameter sponge-coated or completely spongy ice spheres is sufficient to produce an equivalent radar reflectivity factor of 10^7 mm^6/m^3 at a radar wavelength of 3 centimeters.

The puzzling fact that the reflectivity of hailstorms reaches a maximum altitude around the middle of a storm, and decreases both above and below this level can now be accounted for. The temperature at which the highly reflective spongy mixture of both ice and water coats the hailstones must be around 0°C. Since temperature decreases with altitude, the water in this coating should freeze solid at altitudes above the 0° level causing a decrease in a hailstone's reflectivity. Below this altitude level the ice in the coating melts, also causing a decrease in reflectivity.

ELECTRICAL STRUCTURES: A study of the growth and decay of electrically charged areas in thunderstorms was made. For this study, three aircraft were used. Measurements of the electric fields above thunderstorms and the associated cloud top structure were made by the U-2; the C-130A measured the fields alongside the storms and the storm's radar structure; and an F-100F flew directly through them to measure the fields, turbulence, and precipitation forms inside. A good deal of the data relates to the change in electric field structure preceding, during, and following lightning strikes on the F-100. The C-130 and the U-2 also observed close lightning strokes.

AFCRL meteorologists were particularly interested in combining the above measurements to formulate a consistent physical picture of the conditions for the formation of lightning charge centers. Analysis has not yet been completed, but the data indicate that the electrical structure of a thunderstorm is much more complex than is usually pictured. It now appears that areas of negative charge as well as those of positive charge commonly exist in thunderstorm tops.

HURRICANE SPIRAL BANDS: Since 1944, when radar was first used to probe the structure of hurricanes, it was believed that the commonly observed spiral rain bands are generated by relatively narrow regions of convergence which give rise to intense convection. However, by careful radar observations of these spiral rain bands, a group of AFCRL scientists concluded that spiral bands are predominantly of a stratiform type with only a small region of active convection at their upwind ends.

Nevertheless, these small regions of active convection are key features of the model. The hurricane can be pictured as containing a number of convective clouds at a few preferred locations of the cyclone system, usually in the right front quadrant of the hurricane. These convective clouds spew out precipitation particles in the form of ice or snow which stream downwind in the circular wind field, while the region of intense convection moves radially outward. The pattern thus formed is a spiral. But what initiates the small upward velocities which are necessary for the occurrence of stratiform precipitation? This is caused initially by the evaporation and melting of ice crystals in the plume. The evaporation of the ice crystals results in a cooling effect — and thus creates an area of decreased stability which induces the growth of the precipitation farther downwind. Therefore, one of the most novel features of this hypothesis is that the spiral plume itself initiates the convergence (by the cooling process). The convergence does not initiate the spiral plume.

An independent observation which is in agreement with the notion of a cooling mechanism at work is that temperatures within the spiral bands are generally cooler than those outside. Another observation supporting the hypothesis is the fact that only about three or four percent of the hurricane area is covered by "hot" convective (thunderstorm-like) towers. Most of the rain area is contained within the bands of stratiform precipitation.

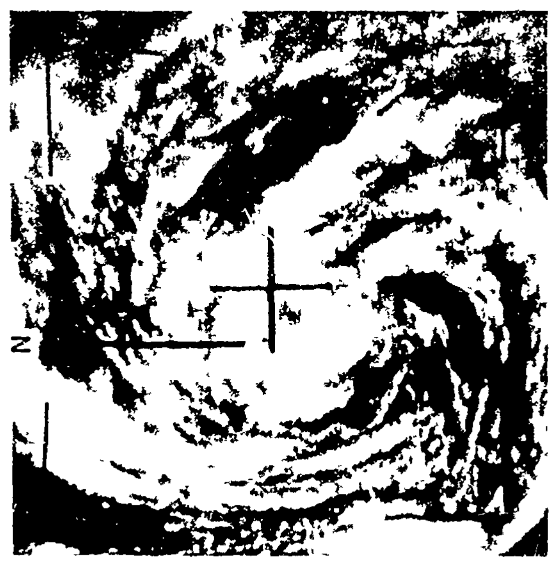
The proposed mechanism is not meant to explain all spiral bands. Other questions, such as the character and arrangement of the essential convective clouds at the heads of the spirals and the maintenance of the spiral band for periods of over an hour, still remain to be answered.

ATMOSPHERIC DYNAMICS

All research in meteorology might properly fall under "Atmospheric Dynamics." Weather has its origin in the dynamic processes of the atmosphere. These processes include world-
2 wide circulations, the mixing of air masses and air layers, localized winds and turbulence, and they include the closely associated variations in temperatures, pressures and humidities. In short, atmospheric dynamics encompasses all components of the huge atmospheric machine fueled by the sun.

The research covered in this section bears on the Air Force need for more accurate weather prediction. Large scale weather modification — much discussed in the popular literature but yet to approach the feasibility threshold — will surely be based on the enhanced knowledge and understanding of fundamental atmospheric processes.

HURRICANE PREDICTION: During the period an AFCRL scientist developed a model of hurricane formation which may eventually make it possible for meteorologists to predict exactly when and where hurricanes will form. In constructing this type of model, certain simplifying assumptions are made. The atmosphere is treated as an "ideal fluid." This fluid is taken as a "physical model" of the atmosphere, and its equations of motion are then derived.



Hurricane spiral bands, like those shown in this TIROS photograph, have been the subject of intensive study by AFCRL meteorologists. These bands of precipitation contain convective systems which hold the key to understanding the processes whereby hurricanes obtain their tremendous energy.

The set of these equations constitutes a "mathematical model" of the atmosphere, which becomes a "numerical model" once the proper data are inserted and the equations solved.

The hurricane model consists of five equations which express relationships among five meteorological parameters. These are: the stream function, which

A chart depicting hurricane growth and movement is shown here with the AFCRL scientist who developed a numerical model for hurricane prediction. The chart represents one stage of a hurricane's development.

gives the pattern of horizontal wind speed and direction at a given altitude, temperature, mixing ratio, vertical motion of air, and horizontal divergence. Of these, only wind speed and direction, temperature, and mixing ratio need be found by direct observation. The other quantities may be calculated from a knowledge of these observed parameters. Additional quantities in the equations, such as amount of latent heat released by the condensation of water vapor, and frictional effects, may also be calculated.

From a set of initial observations of wind speed and direction, temperature, and mixing ratio, the equations are solved and the solutions are stepped forward a small increment of time (five minutes) to generate or "predict" new wind speed, direction, temperature, and mixing ratio which are in turn used to calculate new values for the five unknowns, and so on. The process can be carried on by computer to predict what the wind speed, direction, and location of a hurricane will be at any given time after its formation. However, it should be emphasized that these computations are based on a theoretical model which differs sufficiently from the actual atmosphere so that long-period predictions would greatly depart from reality; and, in addition, long-period predictions would permit accumulation of numerical errors.

The model itself is not new. It was first constructed in 1957. At the time, however, it failed to generate a "mathematical hurricane" from the set of wind and temperature data that were used. Lack of the necessary temperature data prior to hurricane formation was responsible for this failure. When complete wind and temperature data prior to the formation of a hurricane were finally obtained, it was seen that previous assumptions about temperature had been incorrect. The temperature at altitudes where atmospheric pressure is 500 millibars (about 20,000 feet) above the tropical ocean regions (5 to 25 degrees north latitude) where hurricanes form, is an important factor in the equations. It had been assumed that the isotherms would follow the streamlines and that the temperature would increase gradually from north to south. In reality the isotherms have a much more complex pattern prior to hurricane formation. With precise data, the model gave a picture of the hurricane's formation and movement which checked very well with what was actually observed. In fact, it was discovered that this temperature is probably the single most important parameter. Variations of only one or two degrees in 50 km can signal the formation of a hurricane if the isotherms display a certain characteristic pattern.

The speed of the cyclonic winds that develop is proportional to the temperature gradient in such a pattern. If the gradient is too small, no hurricane develops. The model gives wind speeds that were somewhat higher than those actually observed, but the rate of formation and the path which the model predicts are both in very close accord with those observed.

It was also found that the heat released by water vapor as it condenses to form clouds affects the rate at which a hurricane forms, but has little effect on the intensity of its winds. Studies are continuing to determine how temperature, heat of condensation, and other meteorological parameters affect hurricane formation.

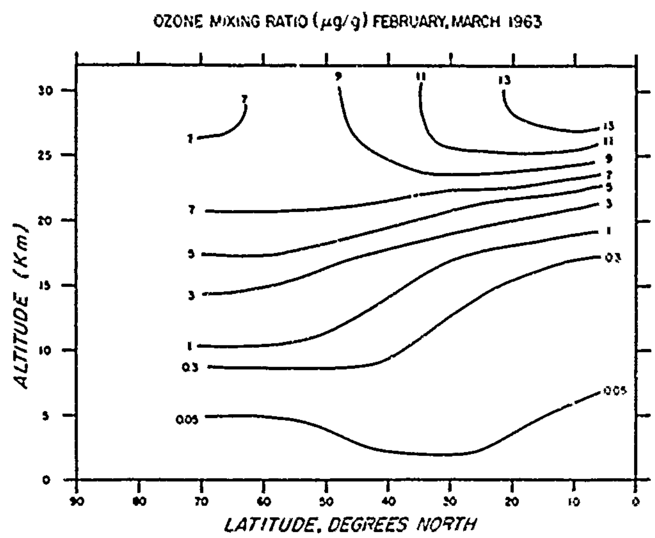
KINETIC ENERGY IN THE ATMOSPHERE: Understanding the relationships between general atmospheric circulation patterns and large scale atmospheric disturbances is a prime goal of meteorological research. Such an understanding is prerequisite to an explanation of how storm systems originate and develop. Although much observational data have been collected on atmospheric flow, both the data collected and their interpretation have come into question because the samples have been too small and time periods were different.

A milestone was reached under a long-term research program on atmospheric flow patterns during the reporting period. The results are the culmination of daily observations taken over a seven year period. During these years, the north-south wind spectra at 500 millibars were obtained by Fourier analysis for each day for north latitudes 30, 45, and 60 degrees. An atmospheric pressure of 500 millibars is roughly centered at 20,000 feet.

These daily measurements provided a spectrum of energies from which various spectral characteristics could be obtained. These average spectral characteristics have, for the first time, given the observer a stable reference point to which he can relate both his future observations and the observations of other investigators. One important characteristic that was uncovered — having significant implications for theoretical studies of atmospheric disturbances — is that the scale size of the disturbances with the maximum kinetic energy does not change with latitude, but averages 5000 kilometers at all three latitudes. Theoretical studies, based upon linearized (that is, mathematically simplified) models, have predicted that disturbances with a scale size of 5000 kilometers should be the most unstable and, therefore, should contain the most energy.

ATMOSPHERIC OZONE: As a strong absorber of electromagnetic radiation, ozone has an active role in the energetics of the atmosphere. The radiative heat balance and thermal structure of the stratosphere and mesosphere are controlled to a large extent by the vertical ozone distribution. The toxicity of ozone and its deleterious effects on certain materials are of particular concern in the operation of high-flying aircraft.

Perhaps the greatest interest in detailed measurements of atmospheric ozone lies in its application, in the passive sense, as a natural tracer of atmospheric motion. The ozone mixing ratio is a conservative property of an air parcel over the lower 95 percent



Average ozone mixing ratio (micrograms of ozone per gram of air) over North America has been derived from data collected by AFCRL's network of 12 ozonesonde stations. Fluctuations in this average ratio are used to trace large-scale atmospheric disturbances.

of the atmosphere. Thus the analysis of ozone variability in time and space provides a unique capability to study the complexities of the circulation processes.

Systematic measurements of the vertical ozone distribution on a broad scale began with the establishment of the AFCRL ozonesonde network program in January of 1963. With the cooperation of the U. S. and Canadian operational weather services and several universities in the United States, coordinated ozone observations are now routinely obtained from twelve stations in North America, which extend from the Canal Zone in the equatorial region to Alaska and Greenland in the polar region. Sounding balloons equipped with a dry chemical ozone instrument are launched simultaneously each Wednesday at each participating station. The program also provides for special periods of daily ascents and is further supplemented by flights with a U-2 research aircraft having ozone and other meteorological instrumentation aboard.

Processed data from the first year of network operation have provided a basic description of the distribution and variability of atmospheric ozone of immediate interest for a variety of research needs. The surprising consistency in the ozone network observations obtained during 1963 and early 1964 indicates that certain generalizations can be made concerning the rates and modes of atmospheric mixing and transport. The surfaces of greatest mixing in the lower stratosphere have a significant slope downward toward higher latitudes. In all seasons, trace substances or contaminants having a significant lifetime tend to assume a uniform distribution along well-defined surfaces whose configuration is given, for example, by the average configuration of the potential vorticity surfaces. The mixing is effected primarily by the large-scale atmospheric disturbances of wave numbers 2 and 3, which are so prominent in the upper troposphere and lower stratosphere. The stream surfaces of greatest mixing, as defined by the ozone network data, are inclined more strongly to the horizontal than the potential temperature surfaces. Under these conditions, the kinetic energy of the disturbances is converted into potential energy. Thus, the energy of the large-scale perturbations in the stratosphere is maintained on the average by a transfer of kinetic energy from the atmospheric stratum near the upper tropospheric jet stream and below.

The ever-increasing library of high resolution ozone data is being used for detailed analysis of the mechanisms of radioactivity, water vapor and ozone exchange between the tropospheric and stratospheric reservoirs and the study of three-dimensional motion associated with such circulation features as mountain waves, extra-tropical storms and explosive stratospheric warmings.

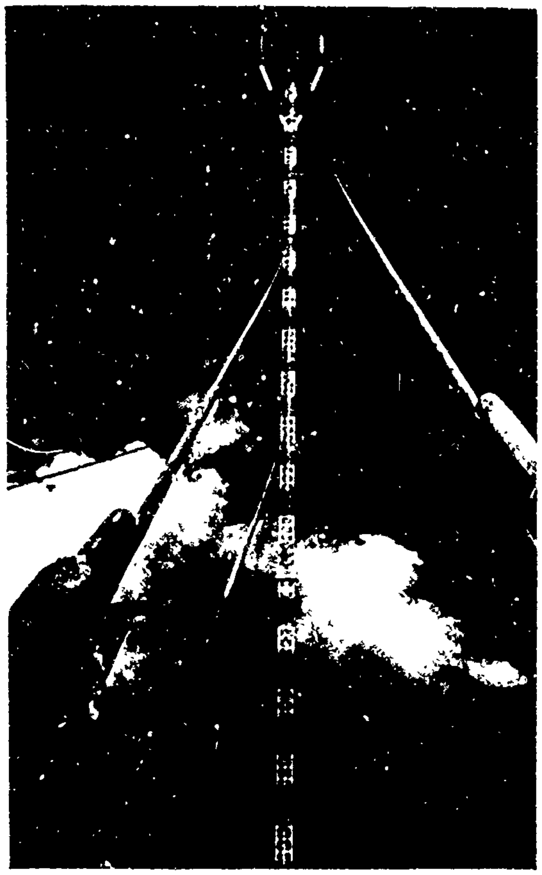
ATMOSPHERIC RADIOACTIVITY: Another tracer of atmospheric circulations is radioactive debris from nuclear tests. Depending on the type, timing, and location of stratospheric injection, radioactive particles stay aloft for periods varying from months to several years. The size distribution of these particles also influences their residence time and plays a role in the selection of best sampling systems for determining absolute concentrations of atmospheric radioactivity. In the AFCRL study, measurements have been made of the size distribution of radioactive aerosols as a function of time within four altitude intervals between nine and 30 km. Balloon-borne, impactor-filter collections of aerosols were measured not only for total-beta radioactivity, but also for strontium 90, zirconium 95, and cerium 144. These individual radionuclides were found to be carried mostly by particles having radii between 0.02 and 0.15 microns, the lower end of the size range for stratospheric natural aerosols. In general, their peak concentrations were between 15 and 21 km, which agree well with the peak in the number distribution of the natural sulfate aerosol.

On specific recommendation by AFCRL scientists, cadmium-109 was released in a 1962 U. S. nuclear test. The idea was to use it as a tracer of high-altitude circulations. During the July 1963 - June 1965 period, concentrations of this tracer in stratospheric samples were determined. Results to date generally support the tentative conclusions drawn from AFCRL's earlier tracer experiment in which rhodium-102, released in 1958, was used. In addition, the cadmium-109 experiment has given some indication of the difference in timing between hemispheres for the major winter disturbances in the polar vortex region.

THE LOW-LEVEL JET: Since early 1961, AFCRL has examined the mechanism of the low-level jet with a thoroughness unmatched by any other research group. Low-level jet streams, as the term implies, are fast moving winds occurring at altitudes between 500 and 2000 feet. They are usually found in regions of flat terrain and they occur most often at night.

Within the past 24 months, studies have concentrated on the growth and decay of the low-level jet streams and associated turbulent fluctuations. In August 1963, a series of experiments was conducted to observe turbulent fluctuations in vertical components of motion. Such fluctuations were measured by means of four continuous-wave sonic anemometers designed by the Laboratory and mounted at heights of 150, 450, 750 and 1050 feet along a 1,480-foot-high TV tower near Dallas. Other instruments had already been mounted at 12 levels from 30 to 1420 feet during the earlier phases of the study, including wind and temperature sensors capable of measuring the average values of these quantities.

More than 50 observational hours have provided a unique set of data on low-level jet turbulence. One observation lasted the entire life-cycle of a jet's formation and dissipation over a 24-hour period. Aircraft carrying wind and temperature probes were flown at tower level on nine occasions to obtain



This TV tower near Dallas, with meteorological sensors spaced at intervals along its length, has proved to be the most productive installation in the country for observing low altitude jet winds that occur at night in the southwest.

near-simultaneous tower-aircraft measurements of turbulent structure in the jet stream at several altitude regimes.

Measurements show that the maximum speed of low-level jets sometimes exceeds 70 mph, even when the wind at ground level a few hundred feet below is only 10-15 mph. This maximum usually occurs at around 1,000 feet in the early hours before sunrise. AFCRL scientists have discovered that a temperature inversion is associated with low-level jets, and that turbulence is partly responsible for the upward movement and eventual breakdown of this inversion.

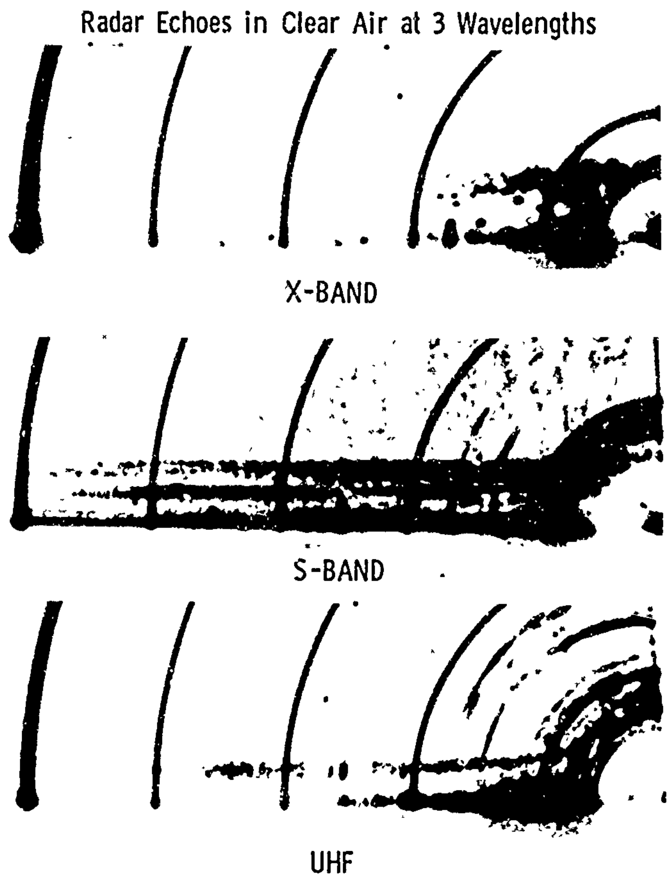
"DOT ANGELS": One form of atmospheric turbulence may be responsible for the well-known radar phenomenon known as "dot angels," which are radar returns from invisible targets. "Dot Angels" are seen at rather unpredictable intervals — though more often on calm, cloudless days. Explanations for these phantom blips have ranged from extremely sharp gradients in the index of refraction, to flying saucers, birds, or insects. During this reporting period, AFCRL meteorologists compiled a complete set of their characteristics from a number of independent radar observations and presented a detailed model to account for the dot angel.

Most dot angels have been detected by vertically pointing radars. The fact that an angel increases in cross-section as it approaches the zenith, provides an essential clue. A curved reflector, presenting a concave surface to a radar beam, would produce this effect. A curved reflector is consistent with the model of a convective thermal or bubble. The air flow within a buoyant bubble is a maximum along the vertical axis, but at the top surface of the bubble the air flows outward and then downward resulting in a sharp gradient of refractive index between the air within the bubble and the environmental air. The bubble is hemispherical, and the "cap" or topmost part of the bubble reflects the radar signal almost perfectly. For the bubble to reflect perfectly, the sharp gradient of refractive index at the top of the cap must be smooth to a fraction of a wavelength. The need for such a well-shaped surface is implied by the maximum occurrence of dot angels on calm days and their disappearance when the surface winds exceed 20 to 25 knots.

This model also accounts for another dot angel characteristic, namely, its appearance as a point source. The angel is seen as a point source because only one point on a spherical reflector, the point at which a plane tangent to the surface of the reflector is perpendicular to the incident beam, will reflect the beam back along the same path.

It was also found that the radar cross-section of the angel increases as it gains altitude, and that this increase is proportional to the square of the distance from the radar to the angel. This fact suggests that the radius of curvature of the atmospheric reflector is directly proportional to altitude, in accord with direct observation that a convective thermal (or bubble) expands linearly with height.

The dot angel study is germane to the problem of clear air turbulence detection (see Chapter X). In cooperation with Lincoln Laboratory of MIT, AFCRL has undertaken a major program to investigate radar echoes from the clear air using three ultra-sensitive radars at Wallops Island, Virginia. Its main objective is to determine whether or not sharp variations in refractive index similar to those associated with dot angels exist in regions of clear air turbulence, and to see if they can be detected and discriminated from other phenomena.



Atmospheric turbulence is responsible for phantom radar echoes, such as these returns recorded by AFCRL scientists at Wallops Island, Va. The Laboratory is conducting extensive research to determine the exact nature of these echoes and whether this effect can be used to detect clear air turbulence (CAT).

SPECIAL PROJECTS

The programs covered in this section are of a somewhat discrete and specialized nature, as against the more generalized studies discussed in earlier sections. Three of the programs are directly related to Air Force operational problems, and were in fact initiated in response to specific Air Force needs.

REFRACTIVE INDEX AND TRACKING ERRORS: Refractive index studies of the atmosphere were conducted in response to an Air Force operational problem — namely, the problem of interferometer tracking errors in the Cape Kennedy area. Precise tracking depends upon knowledge of the atmosphere's index of refraction which continuously varies. There was a strong need for an accurate method for deriving information on the variable index of refraction correction. This information is used as a correction factor in the tracking radars at the time of missile launch.

As a result of the AFCRL study, it appears that the solution for a simple index of refraction monitoring system is through the observation of the detailed moisture irregularities in the atmosphere. In the measurement phase of the program, AFCRL's U-2 and C-130A, as well as two C-131's and an F-100 were used. Sensors aboard these aircraft not only made index of refraction measurements, but also simultaneously observed cloud growth and decay in the general area of the USAF's missile tracking network along the southern coast of Florida. Other instruments were used to make ground observations at 15 special ground weather sites. In addition, radars operated by cooperating groups scanned the area, and occasional use was even made of TIROS cloud photographs.

Preliminary analysis of these extensive measurements has shown that cloud-scale moisture irregularities in the atmosphere can cause tracking errors of the size found in the actual tracking data. The extensive measurements from most of the meteorological sensors were combined to describe in detail the refractive index structure of the atmosphere over the tracking system. This picture in the form of data on grid points was fed into a computer. Lines of sight were passed through this grid, and the simulated tracking errors computed. These analytical methods will be exploited more fully for certain future missile shots where real errors can be determined. Predicted errors can then be compared with actual ones.

DIFFUSION OF TOXIC FUELS: Early in 1961, the Air Force's Ballistic Systems Division asked AFCRL to undertake a research program to gain more information about how turbulent diffusion is related to various meteorological parameters. Behind this request was concern over the potential hazard of toxic vapors from fuels used in the Titan II missile. A detailed study of the diffusion rates for various combinations of atmospheric conditions was conducted by AFCRL at Cape Kennedy and at Vandenberg AFB.

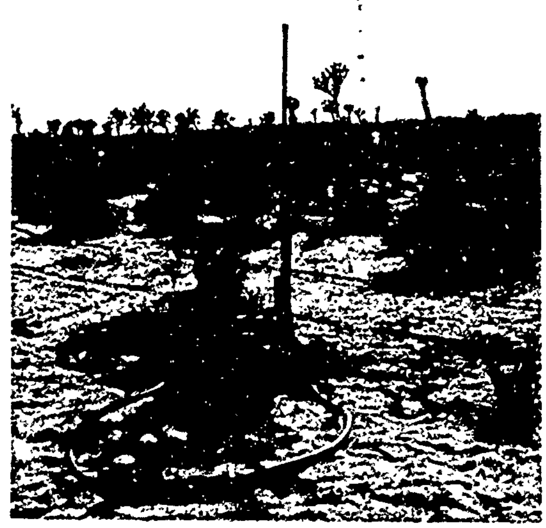
Simulants were released and sampled at distances ranging up to ten miles from the release point while measurements were made of the appropriate meteorological parameters. The 196 field experiments conducted at the two sites produced a large amount of data from which accurate quantitative statements were derived relating meteorological measurements to the diffusion rate of toxic gases. At the same time the field tests were being conducted, AFCRL designed and directed the fabrication and installation of micrometeorological systems, one for each of the missile test ranges.

The systems, which employ a number of new concepts in micrometeorological data acquisition and processing, make use of small digital computers, which permit data to be acquired, processed, and displayed on a realtime basis. The quantitative statements derived from the field experiments were then programmed into the systems' computers so that current estimates of the diffusive power of the atmosphere were available to test range officials on a minute-by-minute basis. The systems have successfully supported every Titan II launch, some with pollution incidents, and have proved essential for range operations in support of later missile systems employing other exotic fuels.

Even before the completion of the Titan II effort, AFCRL was called upon to solve a related problem at Edwards AFB, California. The resulting program, known as Project Sandstorm, was a cooperative AFCRL-AFRPL (Air Force Rocket Propulsion Laboratory) endeavor, supported heavily by personnel of the Air Weather Service. Small solid propellant rocket motors were fired in short bursts, generating "puffs" whose diffusion rates differ from those of continuous plumes, such as were released at Cape Kennedy and at Vandenberg Air Force Base.

All experiments were conducted during the daytime over the desert floor, conditions which provide extremely rapid rates of turbulent diffusion. Sampling devices were placed at various intervals downwind from the static testing stand. During the course of forty-five experiments, more than 20,000 samples were collected together
2 with relevant meteorological and photo-theodolite data. With an analysis of the data and a presentation of the results, Project Sandstorm was successfully completed in June of 1964. The Laboratory provided answers to the question of how far downwind toxic concentrations from a missile firing exist under given weather conditions.

The diffusion of toxic rocket exhaust was studied by AFCRL meteorologists during static firings of solid fuel rockets conducted at Edwards AFB, Calif. AFCRL meteorologists wanted to know how far downwind from the firing stand toxic concentrations are still found. Scores of sampling units, such as the one below, were located at various distances downwind from the test stand.



CLOUD DISSIPATION: During the past few years, AFCRL meteorologists developed and successfully demonstrated an airborne system for making holes in supercooled cloud cover (clouds in which water droplets exist below freezing). The AN/AMQ-20 system, which consists of a machine for making and dispensing dry-ice pellets as needed, has been made operational by the Air Force, and should prove particularly useful at subarctic air bases.

With the successful completion of this project, the AFCRL scientists turned their attention to developing ground-based techniques for dissipating supercooled clouds and fog. During this reporting period, several such techniques were evaluated including the use of tethered balloons, high-powered vertical fans, small drone aircraft, and kites. All these methods were found to be technically feasible. The real problem was to find one that was cheap, simple, and safe. Since the method would be used mostly in isolated areas, it should require a minimum of maintenance and support. Small, inexpensive solid-fuel rockets looked promising at first, but the dry-ice pellets carried aloft were crushed to a useless powder by the launching acceleration. Other methods also had serious drawbacks, but a free-balloon technique was developed which shows great promise and is currently being tested.

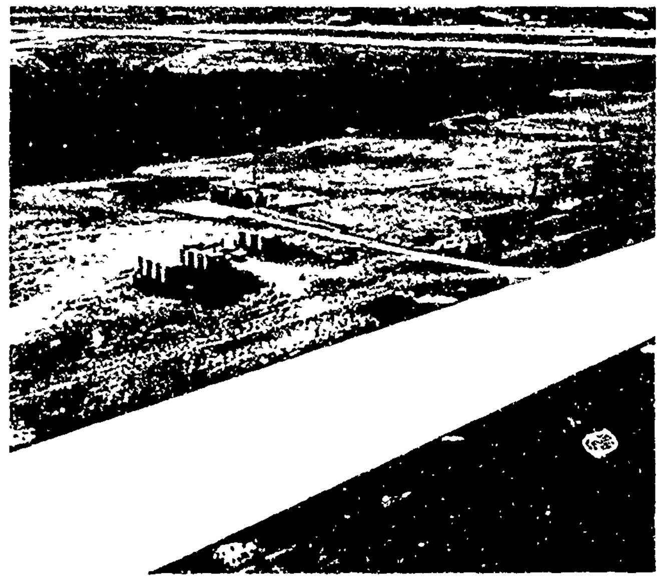
A hole in cloud cover above AFCRL at Hanscom Field was made with a technique developed by AFCRL for dissipating supercooled clouds and fog.

A molded cake of dry ice is suspended below a small weather balloon. The released, slightly buoyant seeding balloon rises slowly into the obscuring fog or low stratus cloud layer. As it ascends, the accretion of rime ice on the cake of dry ice increases to just about balance the weight loss due to evaporation of the dry-ice cake. Thus the dry ice plays a dual role as a dissipator of supercooled clouds and as a simple but effective altitude stabilizing device for the seeding balloon. Conditions in supercooled clouds are such that the balloon would probably stabilize within the cloud or fog layer and cut a swath through it as it is carried along by the wind. Several balloons should be able to dissipate a large enough area for an aircraft to fly through. The balloons and the machine to mold the dry-ice cakes, are both inexpensive and easy to store and handle.

LOCALIZED CONTRIBUTIONS TO WEATHER: One of the more difficult meteorological undertakings is that of determining highly localized contributions to weather. An attempt to measure these contributions will be made in 1965 from a carefully selected site in southwest Kansas. The primary objective of the study is to learn more about the turbulent transport of heat, momentum, and water vapor in the first 100 feet above the ground.

To conduct this study it was essential that a flat area of about one square mile free of all obstructions — trees, houses, towers and so on — be located. It was also necessary that this area be downwind from a larger, five-square-mile open area. The AFCRL equipment will occupy only a small part of the area. Most of the equipment will be housed in two trailers or mounted on a 100-foot tower. Four smaller towers, each one-half mile from the central site, will also be used. Data collected will be edited and stored by a computer-controlled data handling system located in one of the trailers.

One of the key instruments to be used in the study will be the AFCRL three-component sonic anemometer which will provide fast-response measurements of the three dimensional wind field. These measurements along with profile measurements and conventional slow-response meteorological sensors will enable scientists to investigate relations between the vertical flux of momentum and the gradients of wind speed and temperature. Most of the initial observations will be made in the winter wheat section of Kansas during July and August 1965, which is the interval between harvest and planting.



Fog research is carried out at this site at Otis AFB, Mass. This Cape Cod site is subject to frequent fogs at certain times of the year.

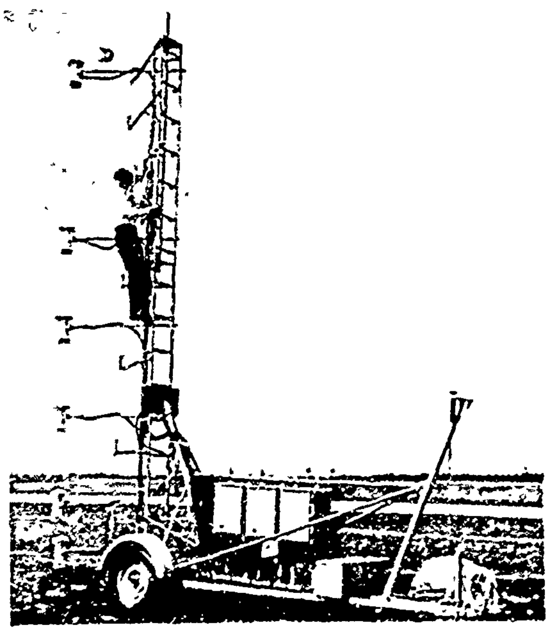
PROJECT CAT FEET: An economical method for dissipating warm clouds and fog has not yet been developed. Although a theoretical study showed that warm cloud dissipation using water as a seeding agent was not practical, this study has been contradicted by experiments which appeared to produce relatively remarkable effects. AFCRL scientists are currently investigating whether these results were a coincidence of nature or due to some unknown effect of the seeding.

More complete knowledge of the natural life cycle and variability of warm clouds and fog must be obtained before this and other promising methods can be properly evaluated and developed for practical application. Project Cat Feet was established to obtain the required information. Work began during the summer of 1964 at Otis Air Force Base, Massachusetts, and consisted of a field measurement program to study the micrometerological, mesometeorological and microphysical characteristics of warm fog throughout its life cycle.

A six-meter mast was instrumented to measure vertical profiles of wind, temperature, and dew-point in a study of micrometeorological phenomena involved in the formation and dissipation of warm fog. Measurements of net radiation at four levels within the six-meter depth were also obtained to study the relationships between the rate of fog dissipation and the rate of change of net radiation with height and time.

Because "advective" fog (fog blown inland from the sea) is the most common fog type occurring at Otis AFB, a mesoscale network of surface observation stations was also employed in the Cat Feet program. This network provided measurements of wind speed and direction, temperature, relative humidity, and barometric pressure at nine locations within a 50-square-mile area southwest of Otis AFB.

Two instruments used in fog research are shown. Above is the laser disdrometer in which coherent laser light is used to photograph size and distribution of particles in a volume of air. The photographic record is a hologram on which all events in three-dimensional volume are collapsed onto a two-dimensional record. The lower photograph is a profile mast used to measure wind speed, temperature and dewpoint at several levels.



The microphysical properties of the warm fog were measured to determine its structure and variability in time and space. The cloud physics parameters that were measured include drop size distribution, liquid water content, electric field, air conductivity, optical density, condensation nuclei concentration, and visibility.

The Air Weather Service supported the Cat Feet program by providing a mobile rawinsonde team. Many new instruments were developed to obtain the detailed measurements required by the Cat Feet program. The most notable device developed for the warm fog study is the laser disdrometer. This instrument can determine the size distribution and shape of both opaque and transparent particles one micron in diameter and larger without collecting them or interfering with their movement through the air. The dynamic range and accuracy of the method makes it suitable for use as a calibration standard as well as for general laboratory and field measurement of aerosols, sprays, fog, raindrops, ice crystals, snowflakes, or any mixture of these.

STATE-OF-THE-ART SURVEYS: Three state-of-the-art surveys summarizing knowledge gained through the use of weather radars were published during the reporting period. *Advances in Radar Meteorology* is a comprehensive survey of all aspects of radar meteorology. *Radar in Tropical Meteorology* is one of the first works of its kind. It reviews the use of radar in the study of tropical meteorology, gathering together a wide array of information on the structure of convective storms and hurricanes. A third review, *Radar Analysis of Severe Storms,* describes and evaluates all known methods for detecting severe characteristics of thunderstorms using incoherent radar.

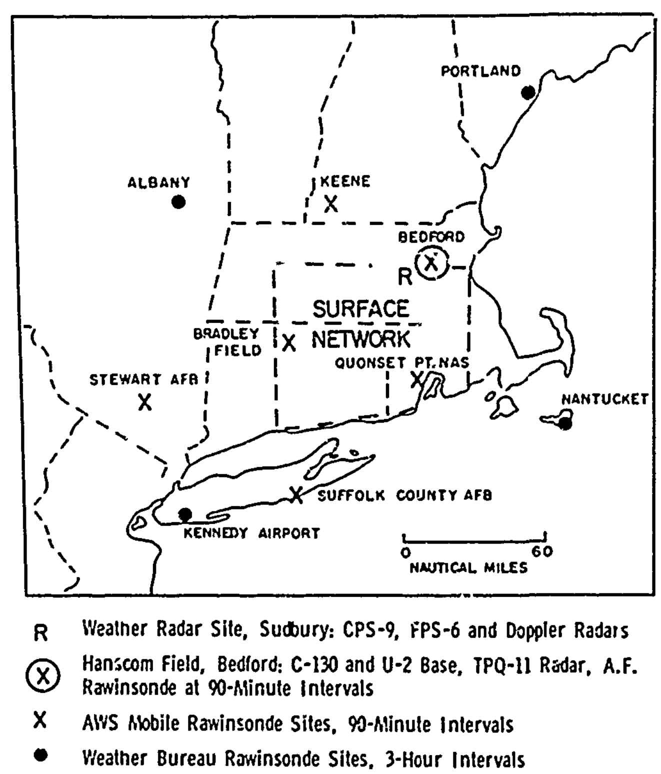
PROJECT STORMY SPRING: The pattern of weather observed at any one time at any one location has evolved from a multiplicity of interrelated phenomena. Hemispheric air circulations have had an obvious part in its formation, but beyond the large pressure systems resulting from general atmospheric circulations, the pattern has been modified by atmospheric processes on the regional and local scale. Regional and local scale (mesoscale) influences have received far less attention than have studies of large-scale weather patterns. Project Stormy Spring is concerned with mesoscale weather structures — that is, structures with an area of about 40,000 square miles.

The Project, conducted in the spring of 1965, placed New England weather under intensive scrutiny. U-2 and C-130 weather aircraft, weather radars, rawinsondes, and weather satellites were used during concentrated periods of simultaneous observations of many aspects of particular weather systems.

The study was largely concentrated in the southern New England states. In weather prediction, mesoscale phenomena give the weather forecaster some of his greatest headaches. He may find, for example, that the 12-inch snowfall predicted 24 hours earlier did in fact occur — but 50 miles west of the city. The AFCRL study is concerned largely with gaining a better understanding of the dynamics of weather systems over a particular region. Such an understanding is fundamental to the problem of more precise local forecasts.

Scientists from all the specialized branches of the Meteorology Laboratory participated in the intensive program of observation and analysis. Stormy Spring observations were conducted between 15 March and 30 April 1965. During this period five systems which passed through the southern New England area were observed by a host of techniques for continuous periods of 24 to 48 hours each.

Some of the goals of the project were: 1) to study the circulation and dynamics of cloud and precipitation bands, high- and low-level frontal zones and mesoscale pressure systems, 2) to determine the distribution of moisture balance and the physics of precipitation growth in various portions of the cyclones, 3) to evaluate the strato-sphere-troposphere exchange processes by examining the ozone structure of the



Project Stormy Spring encompassed the geographical areas shown on the map. The legend below lists some of the equipments used and the frequency with which observations were made during a storm of interest.

upper troposphere and lower stratosphere in relation to the associated circulations and thermal structures, and 4) to develop and evaluate techniques of observation, data reduction and analysis for future studies of this type.

The U. S. Weather Bureau and the Air Weather Service assisted AFCRL by taking some of the observations. Permanent and mobile rawinsonde sites at about 60-mile spacing and operating at 90-minute or three-hour intervals were a basic aspect of the data-gathering network. In addition, a special surface network established to gather wind, temperature, pressure, humidity, and precipitation data from 20 surface sites spaced 20 miles apart was used.

A weather satellite provided cloud photographs, as did the C-130 and U-2 aircraft. In addition, the U-2 aircraft measured distributions of ozone, temperature, wind, and radiation; and the C-130 provided cloud physics, temperature, and wind data. Several weather radars, each with unique capabilities (one of these being a TPQ-11 recently installed at L. G. Hanscom Field), were also used. Project Stormy Spring was one of the most massive and intensive programs for observing weather dynamics over a limited region that has yet been undertaken.

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Growth of crystals in silica gel is a technique for studying crystal growth mechanisms. The crystal grows at a relatively slow rate and remains stationary and undisturbed during the growth process. Crystals in the silica gel medium are clearly visible.

IX Solid State Sciences Laboratory

Much of the Air Force research program in solid state electromagnetics is centered in the AFCRL Solid State Sciences Laboratory. The program covers the ultrapurification of electronic and optical materials, advanced analytical techniques for measuring levels of purity, the growth of a great variety of single crystals, measurement of material properties and phenomena, and the fabrication of electronic devices.

Behind this research are Air Force operational needs for equipments for detection, surveillance, computation, communication, display, weaponry, and control operations. With respect to these equipments, AFCRL hopes to obtain improved radiation and temperature resistance, greater sensitivity, higher power operations, improved speed, enhanced reliability, and decreased size and weight.

The facilities for conducting this research are among the most complete in the country. Indeed, there are few optical, semiconductor or magnetic crystals of any type that the Laboratory does not have the capability of producing. The Laboratory also has facilities for research in single crystal thin film technology. Coupled closely with crystal growth facilities are a host of analytical techniques for determining crystalline structure, purity and electromagnetic properties. For the study of the effects of radiation on materials and devices, AFCRL operates a 1 Mev Dynamitron, a 3 Mev Van de Graaff generator, and a nominal 12 Mev linear accelerator.

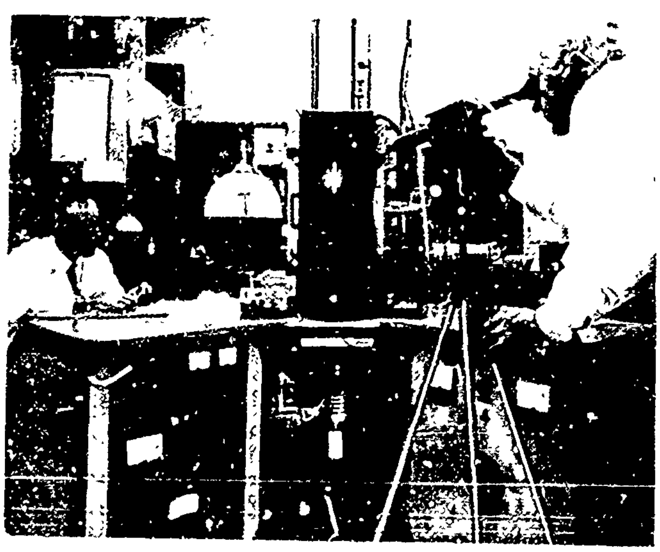
ULTRAPURIFICATION AND ANALYSIS

The requisite first step in solid state research is the preparation of materials of known impurity content. It is the responsibility of those working in the ultrapurification of materials to provide the crystallographer with materials of known impurity concentrates.

As materials of higher and higher purity are obtained, there is a parallel need for improved analytical techniques for detecting minute residual impurities — impurities in the order of only parts per 100 billion. At AFCRL, research in ultrapurification is essentially inseparable from research on improved analytical techniques.

The major programs of the purification program are in four areas: 1) boron chemistry, 2) zone-refining, 3) vapor-phase chromatography, and 4) phase diagram studies.

Three analytical methods — radioactivation analysis, mass spectrography, and emission spectroscopy — are used to evaluate purity levels. During the reporting period, research has enlarged the scope of each method, and increased sensitivity for many elements has been attained. In addition to these methods, used primarily for ultratrace analysis, the more conventional gravimetric, volumetric and colorimetric techniques are used where stoichiometric analysis is required. The Laboratory provides analytical services to other groups both within and outside AFCRL.



Electron beam zone refining of insulating materials presents problems not encountered with metals. Here a sapphire rod is being melted and refined by an electron beam.

BORON CHEMISTRY: Eleme[illegible] boron is a potential high energy-gap semiconductor material. But it must be prepared in high-purity form for appropriate doping. Boron compounds have many potential device applications.

Techniques have been developed for the preparation of massive boron from the hydrogen reduction of the distilled bromide as well as the iodide. The material is extremely pure except for the presence of about 200 parts per million of carbon. The removal of this impurity is being investigated.

A new compound of boron, phosphorus and iodine has been synthesized and characterized. It has the formula BPI_6 and its most interesting application is that it can be decomposed to boron phosphide. This is carried out thermally and the resulting boron phosphide has been obtained both in the bulk and as a thin film on silicon. The boron phosphide has applications as a high temperature semiconductor material.

Boron arsenide has been synthesized by direct combination of the elements. This material should prove to be an interesting semiconducting compound with a different carrier mobility than boron phosphide.

ZONE REFINING: Zone refining is a widely used technique in which the material in solid form is moved past a heating element and is melted during passage. The impurities that are soluble in the molten phase are swept toward the end of the charge as the liquid zone is moved. Several passes are made and with each pass greater purity is obtained. Although zone refining is widely used in semiconductor purification, only one batch at a time can be processed. No other laboratory, it is believed, is carrying out a research program in continuous zone refining. Continuous zone refining may become a widely applicable technique for the ultrapurification of electromagnetic materials.

Where large quantities of ultrapure material are required, the continuous system has two distinct advantages over the multistage batch system now commonly used. In tests, the continuous system has been shown to produce a controllable quantity of product with every pass, and the product it produces has a solution concentration very close to the ultimate. AFCRL has designed and built two continuous zone refining systems.

The steady state equations of the three existing theoretical models of continuous zone refining systems reported by other investigators were examined during the reporting period and found to be in error. These errors were corrected. A technique was developed by which the intrinsic parameters of all continuous zone refining systems could be nondimensionalized. Nondimensional steady state equations were derived which were capable of being programmed and run on an electronic computer. The results of these computations, in graphical form, provided the means for a rapid comparison of the effectiveness of all continuous zone refining models or systems. These same curves were used to evaluate how variations in various parameters affect the purity of the product produced.

Theoretical models of two new continuous zone refining systems have been developed as a result of this work. A matter transport system was built and tested, which increases the flexibility of design of a continuous zone refining system and can increase product purity. A continuous float zone refining system has been designed but has not yet been built or tested. If the experimental problems associated with this system can be solved, it will be the most powerful zone refining tool yet developed for the production of ultrapure materials.

Atmospheric dust can severely contaminate materials during the ultrapurification and analysis stages. This special room, with its large air filtering system, provides a clean atmosphere, thus permitting a more reliable determination of material composition.

VAPOR PHASE CHROMATOGRAPHY: A complete experimental system for the evaluation of vapor phase chromatography as a technique for the preparation of ultrapure volatile intermediates of semiconducting materials has been devised. The preparative chromatography has been modified and necessary auxiliary equipment assembled. Preliminary runs using silicon tetrachloride have been carried out and samples of the collected effluent have been hydrolyzed to silicon dioxide. The purity of these samples is being evaluated by mass spectrographic and emission spectrographic analysis. An apparatus has been built to decompose thermally the silicon tetrachloride effluent to silicon. Analysis of the purity of this silicon will be performed. This work, it is hoped, will lead to a demonstration of the effectiveness of the chromatographic technique.

PHASE DIAGRAMS: Experimental studies on the zone refining of a number of eutectic forming systems — materials which alloy at some minimum melting point — have been made. The systems investigated were triphenyl antimony-benzoic acid, triphenyl antimony-napthalene, and triphenyl antimony-biphenyl. The use of radioactive antimony (Sb^{121}) as a tracer provides a nondestructive in situ analysis, and permits successive zone passes to be made on the same sample tube. The counting instrumentation has a punch tape output which not only provides a convenient method of data processing, but permits its analysis on the basis of the various zoning models. In these studies, various profiles were obtained which depart from those expected on the basis of theory, and from the phase data derived by the Laboratory from thermal analysis.

The three systems investigated were of the single eutectic type. Assuming ideal conditions, the concentration profile resulting from the zone melting of a eutectic type mixture is easily predicted. In these experiments typical concentration profiles were not observed. Although thermal analysis indicated no solid solubility, "apparent K's" were measured. The apparent K's reflected the variability that existed in the liquid profile resulting from different zoning rates and ambient temperature conditions.

SAMPLE ANALYSIS: During this reporting period the analytical group performed a total of 472 analyses. Of this total, 379 samples were submitted from various groups within the Solid State Sciences Laboratory. Of interest is the fact that 93 samples were analyzed for other laboratories, Government agencies, or contractors. The techniques and instruments available at AFCRL are not widely found elsewhere. These analyses gave Laboratory scientists access to newly developed processes or materials from outside the Laboratory.

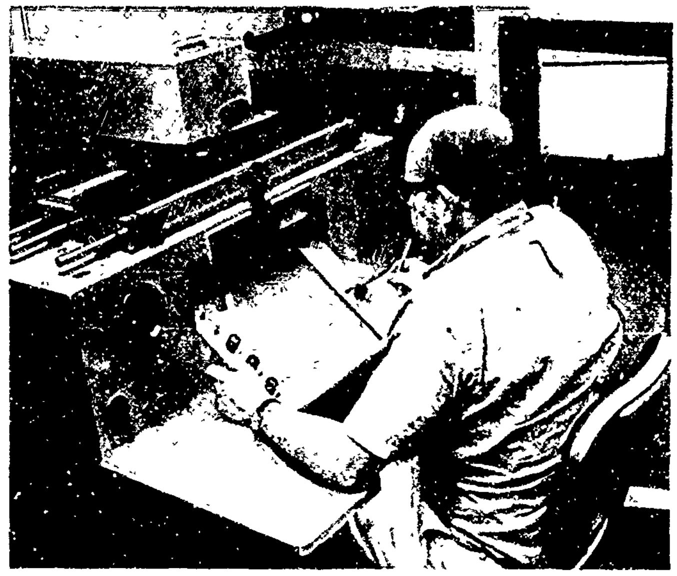
The 472 analyses represented about 200 different materials indicating the wide range of substances now undergoing Laboratory investigation. This number does include, however, various intermediate substances and compounds.

COMPUTERIZED GAMMA SPECTROMETRY: Neutron activation analysis is by far the most sensitive method of detecting trace impurities in solid state materials. It has the drawback, however, of being slow, tedious, and expensive. Because of these drawbacks, the Laboratory has been exploring new techniques for speeding up this analysis.

More than 80 elements, when irradiated by neutron bombardment, have isotopes which become gamma emitters. In radioactivation analysis, these radioisotopes are usually separated radiochemically. But AFCRL has found that modern multi-channel gamma analyzers can perform this separation automatically. Although poor resolution of the gamma detector limits the number of peaks which may be thus separated, by using computer techniques, the complex spectrum can be analyzed into its component parts and the contribution of any particular gamma isotope can be evaluated. In the computer program, the complex curve is treated as the sum of the individual isotopes' photopeaks (Gaussian distribution) plus Compton scattering (exponential distribution). The computer unravels these from various possible permutations. The analytical program as finally developed will allow the solution of a 100 by 100 matrix — far beyond the resolution capabilities of present gamma spectrometer systems.

It appears that these techniques will provide a vastly speeded-up technique for the analysis of trace impurities in ultrapure materials.

EMISSION SPECTROGRAPHIC RESEARCH: One of the first applications of the laser in analytical chemistry has been its use as the excitation source of an emission spectrograph. In January 1964, AFCRL's newly developed laser spectrograph was placed in operation. In this instrument the laser beam is focused on the sample and the light resulting from the thermal excitation of the sample is analyzed by the spectograph. Because of the coherency of the laser beam, very small volumes can be sampled and micrograin boundaries and similar defects studied. The volume being vaporized is a function of the nature of the sample, its thermal conductivity, melting point, heat of



Many techniques are used to determine the purity level of highly refined materials. In the top photograph, a spectrograph obtained by conventional emission spectroscopy is being analyzed. In the lower photograph, residual impurities irradiated and deliberately added to a semiconductor material prior to the refinement process are being measured by a scintillation counter.

vaporization and other factors. (Sample spot size is normally around ten microns in diameter.) The degree of sample excitation to be expected is not yet well understood and a theoretical model of the entire interaction process is under study.

CRYSTAL GROWTH

The single crystal is distinguished from other forms of matter by the repeated, geometrically-ordered arrangement of the atoms or ions. This definition applies both to a material in bulk or granular form and to a thin film of a material only a few microns thick. It is this attribute of periodicity in the crystal which gives it many of its interesting and technologically worthwhile properties. In addition, crystals can be made even more interesting and useful by the intentional introduction of foreign ions which change the energy structure. A good example of this is aluminum oxide, which when grown in single crystal form becomes sapphire — a material which is relatively inactive as an electronic material. But with the addition of minute amounts of chromium, the crystal becomes ruby, a basic laser material.

Research in crystal growth has three objectives: 1) to develop improved methods for growing crystals, 2) to discover new types of crystals with improved or unique performance characteristics, and 3) to gain sufficient understanding of crystals and crystal growth processes so that crystals with certain desired performance characteristics can be precisely tailored.

To conduct its crystal research, AFCRL has approximately 25 furnaces, crystallizers, and presses. During the reporting period, AFCRL passed the 100 mark in the number of crystals synthesized.

The interest in semiconductor films has intensified since the last report. Controllable single crystal film deposition techniques add a very desirable new flexibility to device design and integrated circuitry. Thin film techniques may make possible the formation of some semiconductors, or semiconductor mixtures, that would be technically impossible with bulk crystals. Since there are a great many high energy gap semiconductor device materials that AFCRL is anxious to look at for their device potential, thin film provides an economical technique for obtaining such materials for study.

The acquisition, cataloging, and dissemination of state-of-the-art data resulting from Air Force sponsored and allied research efforts are also responsibilities of the Laboratory. About two and one-half years ago, the Laboratory started a bibliography on crystal growth. This work was completed in March 1964. Phase diagrams of crystal growth were also included in the bibliography. The system currently consists of approximately 5000 cards.

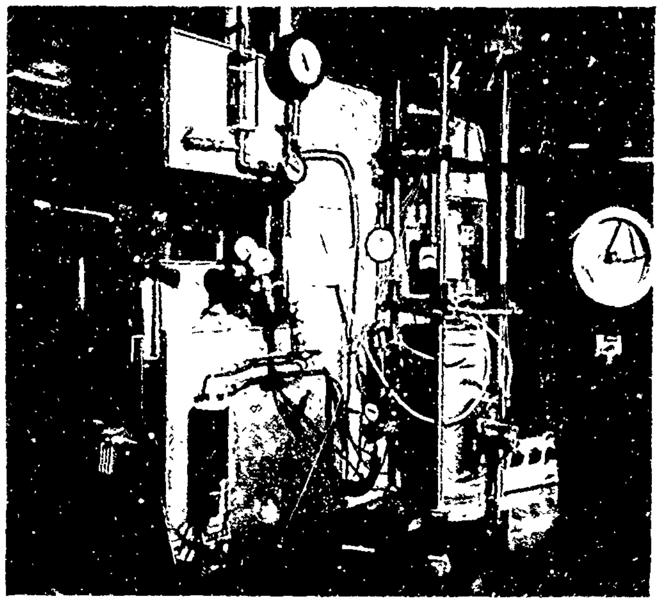
THERMAL ANALYSIS TECHNIQUES: The basic structure of a material subjected to extreme ranges of pressure and temperature may be changed. Both the lattice structure of the material and the alignment of atoms or ions within the crystal can be altered — possibly obtaining an entirely different form of material. The best known example of this is the conversion of graphite to diamond. This conversion in crystal structure is known as phase transformation.

One method for detecting a phase transformation is by differential thermal analysis (DTA). This is based on a change in the thermal characteristics that occur when a material undergoes a phase transformation. This change is measured by plotting the difference in output between a sampling thermocouple and a reference thermocouple encased in a special reference body. Both thermocouples and the reference body must have identical thermal environments. The accurate measurement of temperature becomes more difficult as the temperature range is extended. Furthermore, this difficulty is compounded enormously when the sample size is limited and the entire volume is subjected to pressures in the order of millions of pounds per square inch.

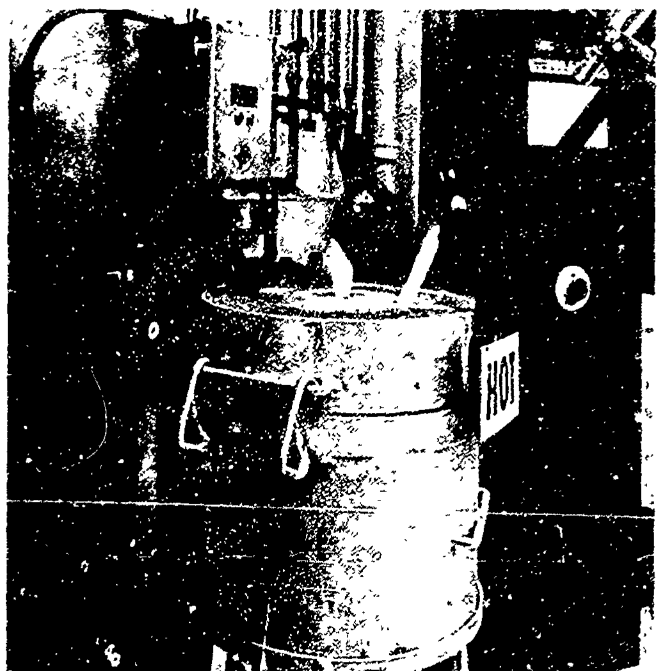
To measure temperature excursions under these extreme environments, the Laboratory has been conducting experiments into new measurement techniques. Some of the detriments encountered under high pressure conditions are shearing of the thermocouple wires, unpredictable thermal behavior of reference materials, distortion and displacement of thermocouples within the sample and reference body, and loss of limited sample space taken up by the reference sample.

To alleviate these problems, AFCRL has replaced the reference body and the reference thermocouple by an electronically derived reference signal. In this scheme, a change of temperature is measured and plotted versus time or temperature while the sample of interest is being subjected to pressure. This method employs a single thermocouple located in the test sample and an external reference. The reference signal is electronically derived from the single thermocouple used in the sample.

To distinguish clearly between the original dual differential thermal analysis (DTA) technique and the present method, this system is termed DATA,

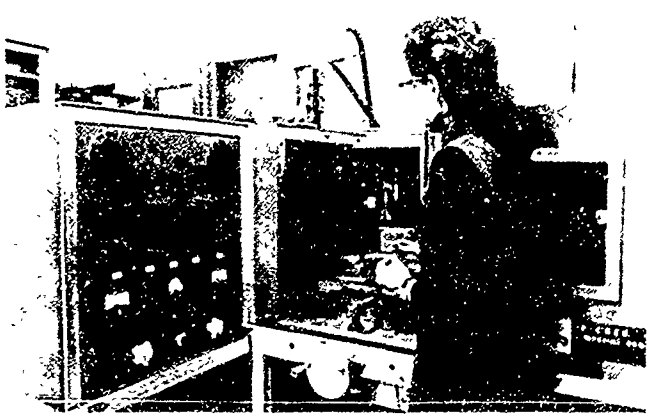


The furnace in the upper photograph is capable of sustained operation above 2500 degrees C. The furnace in the lower photograph is used to anneal single crystals of ruby. Annealing-heating close to the melting point of the specimen results in a relaxation of strain and the reduction of structural imperfections.



Differential Analog Thermal Analysis. In addition to physical advantages, DATA provides increased sensitivity and detail at lower temperatures. Research continues on DATA with studies of the heating and cooling curves for tin in the Laboratory's tetrahedral anvil press at discrete pressures up to 100 kilobars (approximately 1.5 million psi).

Conventional differential thermal analysis (DTA), on the other hand, remains a sensitive method of determining thermal properties of materials at elevated temperatures and is used in many basic aspects of single crystal technology where sample size and pressure effects do not complicate the measurement. Some of the properties capable of being determined, in addition to crystal structure changes at high pressures and temperatures, include: melting and freezing points of materials, oxidation and reduction reactions, heats of fusion, specific heat capacities, chemical kinetics, and Curie points (temperatures at which materials lose their spontaneous or permanent magnetization).



This single crystal orienter with x-ray pattern display is a unique tool for positioning and analyzing single crystal materials.

As part of its program on growth and characterization of single crystals, the Laboratory must measure most of these thermal properties. However, up to now, DTA equipment has not generally been used above 1200 degrees C either as a qualitative or quantitative analytical tool for the study of materials. As temperature is increased above this, so are the problems of DTA. Because accurate DTA data above 1200 degrees C are vital to many of the Laboratory's programs, a differential thermal analysis apparatus capable of determining phase transitions and other properties up to 1620 degrees C was recently designed, constructed, and put into operation. This design is such that a tubular silicon carbide heating element, capable of providing temperatures up to 1650 degrees C in air, serves not only as the source of heat, but also as the furnace chamber.

The heretofore limitation of poor signal-to-noise ratio at these temperatures is overcome by improved circuitry, while a unique platinum sample holder greatly diminishes problems associated with non-identical thermal conditions. Excellent reproducibility of data with this improved instrument has been established. This advanced DTA method is currently in use in the Laboratory and is being correlated with x-ray, chemical, and microscopic analyses in order to identify phases under study.

NEW HIGH PRESSURE, HIGH TEMPERATURE EQUIPMENTS: The work previously mentioned on DATA was done with the AFCRL tetrahedral anvil press which has been in operation at AFCRL since 1958. During the reporting period, two new high temperature, high pressure equipments were installed in the Laboratory.

One of these — also of tetrahedral

design — permits x-ray observations during actual operation. Thus, for example, transitions from graphite to diamond can be observed as they occur. This equipment has been designated the x-ray press. It consists of a tetrahedral anvil press and a high power rotating anode x-ray tube and associated control equipment. The press has been operated at pressures in excess of 100 kilobars with satisfactory performance. The power output of the x-ray tube appears to be approximately 60 times that of the best commercially available x-ray diffraction tubes.

The entire system was placed in full operation in July of 1965. A film camera was initially used for detection of the diffracted rays. Later, scintillation counters will be used.

The second new press, a modification of the Bridgman opposed-anvil apparatus, is designed to more effectively apply pressure and temperature parameters. This oscillating squeezer has the advantage of speeding the rate of reactions and transitions, especially in the relatively low temperature range of 100 to 200 degrees C. This means that materials can be synthesized at high pressures at significantly lower temperatures. Phase transitions characterized by prohibitive reaction kinetics can also be more easily obtained. A case in point is the synthesis of coesite (SiO_2) at room temperature using the new press.

This pressure apparatus has been operated above 120 kilobars (1¾ million pounds per square inch) at 300 degrees C with tungsten carbide anvils. It has also been operated above 700 degrees C at 40 kilobars. These two examples help to define the pressure-temperature capability of the apparatus. Pressure-temperature limits of operation are imposed by the strength of the anvil material. The temperatures noted above can be more than doubled by using more complicated methods of heating and simple geometry to protect the anvils.

AUTOMATED CRYSTAL GROWTH BY FLAME FUSION: The flame fusion or Verneuil process was developed over 60 years ago. The best known crystal product of the Verneuil furnace is the ruby, still the leading laser material for high power operation.

The flame fusion process consists of feeding a fine powder of the material to be grown into a high temperature torch directed downward at a pedestal or seed crystal. The feed particles are melted in the torch and fall upon the pedestal. As the seed crystal is enlarged by the molten, impinging particles, the pedestal is slowly withdrawn so that the position of the liquid-crystal interface is maintained at a constant level. With this technique, large single crystals of sapphire, ruby, rutile, spinel, and other oxides are grown. Crystals grown by this technique, however, are too often characterized by excessive mechanical strains and variations from chemical stoichiometry, doping inhomogeneities, and improper control of ionic valence. These faults result from inadequate temperature and other parameter controls. The human monitor during the growth process does not have the ability to make the minor, but important, changes necessary to achieve crystalline perfection.

To overcome some of these difficulties, AFCRL, in collaboration with the University of Michigan, initiated in 1962, work on an improved, completely automatic Verneuil furnace. This furnace was designed to produce single crystals under carefully controlled and reproducible growing conditions. This

This high pressure, high temperature apparatus has been used by AFCRL since the late 1950's to grow diamonds and to evaluate other materials subjected to ultrahigh pressures.

is of utmost importance. If a particular ruby crystal, for example, demonstrates exceptional performance in a laser, the current state of the art does not permit its duplication.

Final design of the furnace was completed during 1964 and construction will be completed during the summer of 1965. Some of the capabilities designed into the apparatus include the following: the furnace is fully automated with automatic flame control, retraction of the pedestal, power feed rate, and cooling control; the machine can be operated on fully automatic, fully manual, or a combination of these. There is capability for automatic shut-off in case of serious failure, while less serious difficulty will merely activate acoustic and visual alarms.

The feed mechanism is electrically operated with a silicon controlled rectifier so that vibration intensity (growing crystals are extremely sensitive to minute vibrations) and the feed rate can be precisely monitored and controlled. The pedestal raising assembly is servo-controlled with a photocell serving as the sensing element. The growing chamber is surrounded by six portholes used for temperature sensing, photocell control, high speed photography, and other uses demanded by scientific investigations. The machine operator is able to observe boule growth continually by means of projection on a screen located directly in front of the console. (The boule is magnified four times.) The apparatus possesses auxiliary heating to diminish the temperature gradient in the growing chamber and to achieve simultaneous annealing of the boules.

CRYSTAL PERFECTION STUDIES: Tremendous complexities are involved in placing individual atoms in the specific positions required for a perfect crystal lattice. In many growth processes, as many as 10^{20} atoms are positioned in the lattice each second. One misplaced atom per ten thousand can mean enormous amounts of misfits in small volumes of material.

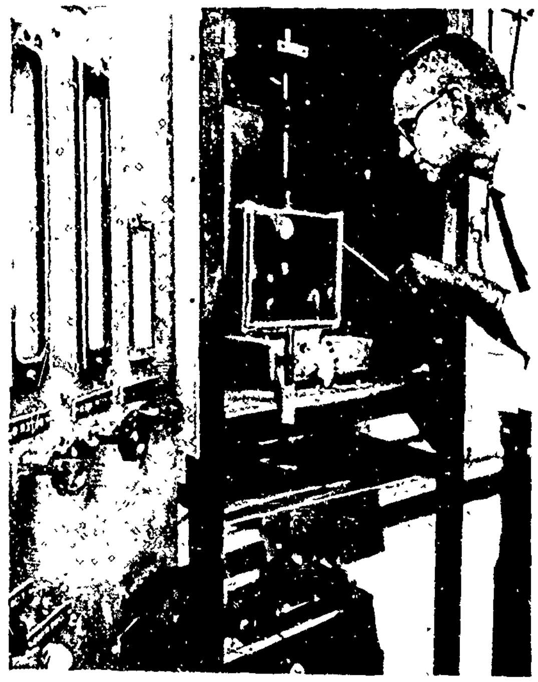
The usefulness of crystals is limited by their defects and deviations from the ideal rather than by their inherent characteristics. To learn more about the flaws in single crystals grown at AFCRL and their effects on properties, the Laboratory is studying the dislocation structures in ruby and sapphire as obtained from the Verneuil furnaces. (A dislocation is a linear discontinuity in the orderly arrangement of atoms in a crystal, as contrasted from a point defect which results from an ion being incorrectly positioned or not being positioned at all.) This study was undertaken as a background for the effect of dislocation structures on laser properties.

Verneuil ruby and sapphire crystals

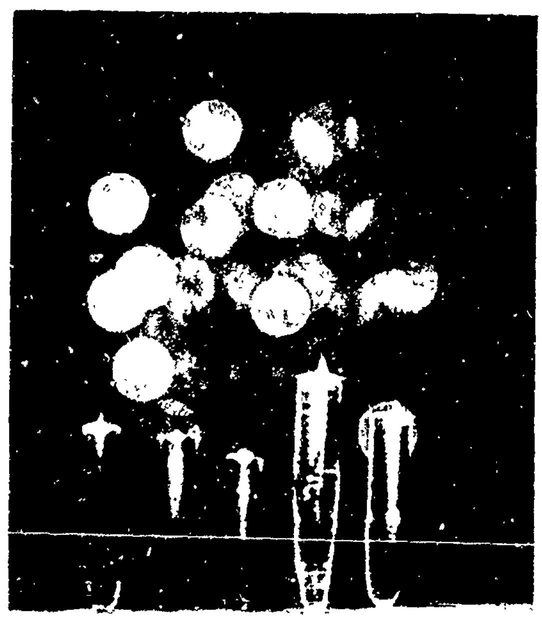
whose C-axes were at 0, 60, or 90 degrees to their growth axes were examined. The crystals grown at the Laboratory allowed comparative examination with annealed 90 degree ruby crystals obtained from commercial suppliers. Sapphire crystals grown from high temperature fluxes were also studied. The dislocation structures were examined by use of chemical polishing and etching techniques. These techniques, developed at AFCRL, removed the uncertainties of dislocation creation and rearrangement usually resulting from mechanical or flame polishing. Dislocation densities were then expressed as the number of etch pits per square centimeter of surface area. Photographic evaluations gave primary evidence that the etch pits corresponded to line imperfections.

These studies have provided a quantitative determination of the dislocation structures in Al_2O_3 as affected by growth technique, crystal orientation, chromium ion doping, and annealing. Among the results: 1) the average prismatic edge dislocation density of Verneuil sapphire crystals (3.0 x 10^5 per cm^2) was unaffected by crystal orientation, but slightly altered with chromium addition; 2) the substructure of 0° crystals was more dense and complex than that of 90 degree crystals; 3) the average basal dislocation density of Verneuil crystals was 2.0 x 10^6 per cm^2 and was unaffected by crystal orientation and chromium addition, and 4) the dislocation content of crystals grown from flux systems was appreciably lower than that of Verneuil crystals.

A new oxy-hydrogen burner, designed under contract, was constructed and put into operation in one of the AFCRL flame fusion furnaces. This burner is a three tube post-mix type with a design



The Verneuil furnace is one of the most widely used crystal growing equipments. A principal product of this furnace is ruby crystals, several boules of which are shown in the lower photograph. Ruby is still the best laser crystal for high power operation.



which avoids the sharp, turbulent mixing zones of the usual tri-cone burner. A water cooling device has been developed for use as an attachment on the burner when growing crystals of materials with melting points above 2200 degrees C.

With the burner, single crystals with diameters in excess of ¾ inches have been grown. These crystals include rutile (TiO_2), strontium titanate, nickel oxide, spinel ($MgO{\cdot}Al_2O_3$), sapphire, and ruby. These crystals had far fewer dislocations — by an order of magnitude — than crystals grown using the conventional dual channel burner.

FILM GROWTH BY CHEMICAL REACTIONS: Epitaxial growth consists of depositing a thin film of one material on another — usually designated the substrate — in such a way as to achieve a chemical bonding between the two. The material being deposited is first vaporized. When it solidifies on the substrate, it assumes single crystal form. Epitaxial film growth by chemical reactions in open tube flow systems was greatly extended by the Laboratory during the reporting period. Systems now routinely available, or being investigated, are:

1) silicon on silicon substrates
2) germanium on germanium substrates
3) gallium arsenide on gallium arsenide substrates
4) silicon carbide on silicon carbide substrates
5) germanium on gallium arsenide substrates
6) gallium arsenide on germanium substrates
7) silicon carbide on silicon substrates

From the semiconductor viewpoint, the first four of the above epitaxial systems are "homoepitaxial" systems, and the last three are of the "heteroepitaxial" type. Homoepitaxial growth of silicon has become a routine technique. Present work in this area is now aimed at improving control of layer resistivity, electrical quality of grown p-n junctions, and growth into "windows" in SiO_2 masks.

Heteroepitaxial growth of GaAs films on Ge substrates is also done routinely. Present efforts are directed toward improving control of doping conditions and substrate preparation. In connection with the latter, a new chemical polishing technique employing NaOCl solutions, has been developed which produces damage-free and pit-free flat surfaces hitherto unattainable with other etches. The technique of GaAs epitaxy employed here is one of synthesis in that elemental Ga and As is used as source material rather than the more expensive polycrystalline GaAs itself. It is a convectional transport process in which As vapor is transported to the seed crystal in a stream of H_2, while Ga is transported as GaCl formed by HCl reacting with Ga at 950 degrees. At the lower seed temperature (700-800 degrees C), a disproportionation reaction occurs wherein three molecules of GaCl decompose to form two atoms of Ga and one molecule of stable $GaCl_3$. The elemental Ga and As at the seed grows into a film of GaAs. These films have good surface morphology, while x-ray and electron diffraction patterns, as well as electrical properties, indicate a high degree of crystal perfection.

It has been found that GaAs-Ge heterojunctions formed by growth of the former on the latter have poorer electrical characteristics than those formed by epitaxial growth of Ge on GaAs. An attractive technique for this

Apparatus for silicon carbide film deposition shows clearly the incandescent substrate holder. With this apparatus, single crystal films of silicon carbide are deposited on sapphire substrates.

in open tube flow systems is the H_2 reduction of $GeCl_4$. Whereas this technique is a tried and proven one for homoepitaxy of Ge, its adaption to Ge epitaxy on GaAs presents problems due to etching of the latter by $GeCl_4$ and also due to evaporation of As from the GaAs substrate. These problems are under current investigation.

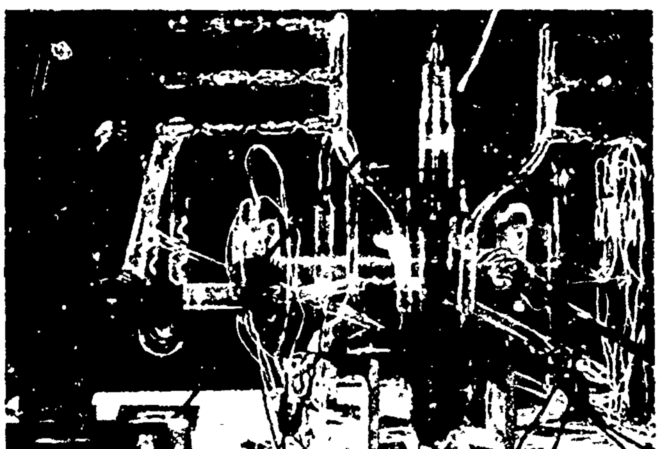
The synthesis and epitaxial growth of SiC films for use in high band gap, high temperature device applications has great potential. Thermodynamic calculations indicate the feasibility of formation at temperatures between 1000-1300 degrees C, which is well below previcusly calculated transition temperatures (2000 degrees C). The growth process under investigation is the simultaneous H_2 reduction and/or pyrolysis of $SiCl_4$ and a carbonaceous gas or vapor in an RF heated reaction chamber. Initially, CCl_4 is being used as the carbon source, but also pure hydrocarbon gases are being investigated. Kinetic studies of the several systems will be performed as well as gas phase doping experiments and film growth in the presence of oxide masks. Experimental films show excellent characteristics.

FLASH EVAPORATION: Flash evaporation is a thin film crystal growth technique involving the instant vaporization of small material particles. This technique is particularly adapted to compound semiconductors in which one constituent is more volatile than the other. The vapor condenses, without change in composition, onto any available substrate. When single crystal film depositions are required, a single crystal substrate must be furnished together with means for heating and controlling its temperature. This temperature and the temperature of a crucible (or evaporator) are the critical variables controlling single crystal deposition since they both affect the surface mobility of the depositing atoms. A program built around this technique has been initiated.

The flash evaporation process is carried out in a bell jar at a pressure of 10^{-6} torr. Under the action of a vibrating mechanism, powdered material moves along a chute and falls in a continuous stream into an evaporator, a resistively heated tantalum cup. The temperature of the evaporator is held between 1350 degrees C to 1800 degrees C. Each grain of the evaporant is vaporized almost instantaneously. The vapor thus produced condenses on a substrate positioned directly above the evaporator. The substrate is uniformly heated by resistance. This method has been employed in the preparation of a large series of mixed III-V compounds.

Highly oriented single crystal films of GaAs and Ge have been deposited onto Ge single crystal substrates. Diodes of these materials were fabricated for study. GaAs-Ge and GaAs-GaAs diodes, prepared by "p" GaAs deposited on "n" Ge substrates and "p" GaAs on "n" GaAs substrates gave characteristics typical of a soft diode.

Work is continuing in an effort to improve crystal perfection of films and to increase doping concentration. Electron diffraction evaluations are being supplemented by double beam x-ray techniques to better establish the crystal perfection of deposited films as well as the perfection of the substrates. Rocking curve measurements by double beam techniques show a lower degree of crystal perfection than is shown by electron diffraction patterns. This is in agreement with the mediocre-to-poor electronic properties observed for most films and film diodes.



High vacuum sputtering of compound semiconductor films is accomplished with this apparatus. In the center foreground, the cross shaped sputtering chamber is clearly visible.

SPUTTERING: Film deposition by sputtering is accomplished when an energetic ion hits a target material with sufficient energy to knock off atoms. These atoms are then deposited on a suitable substrate. Sputtering as described here is an old and widely applied method of film formation, but was customarily done in a glow discharge which meant a comparatively high pressure, low mean free path of the depositing atoms with relatively little control or knowledge of the energy of the sputtered atom. The major distinguishing aspect of the AFCRL technique is that all sputtered film deposition occurs in a carefully controlled low pressure discharge where the mean free path of the sputtered atom is greater than the target to substrate distance. This makes it possible to control and investigate the effect of the extra energy of these atoms on film structure and properties.

An added feature of this investigation is the adaptation of mass spectrometry to sputtering to determine the effect of residual gases on the resulting deposits. Considerable experience had been developed in the past on the analysis of residual gases by use of a small mass spectrometer. A differentially-pumped omegatron mass spectrometer is used to monitor the ambient gas before, during, and after the sputtering operation. Basically, the omegatron operates like a cyclotron. An electron beam inonizes the residual gases, and a magnetic field collimates the beam and causes the ions to move in a circular path at their cyclotron frequency. When the applied RF field is in resonance with a particular ion species, the absorbed energy causes the ion to spiral out until it is collected. The ion current is a direct measure of the abundance of the gas that has the proper mass to charge ratio to be resonant at the applied RF energy.

In the experimental investigation, an all-glass high vacuum system was used. Experiments were carried out in argon at 3 x 10^{-3} torr. The system permitted the deposit of two films simultaneously at variable temperatures. This program has resulted in films of germanium that have been deposited with various degrees of single crystallinity onto germanium, gallium, arsenide, quartz, and mica substrates. The deposition rate has been from three to nine angstroms per minute. The deposit has varied from amorphous to random polycrystallinity, to various degrees of preferred orientation, and finally to single crystalline form. Temperature ranges from 80 to 650 degrees C were investigated, with single crystalline deposits obtained at temperatures as low as 300 degrees C.

PROPERTIES AND ANALYSIS

When the crystallographer is able to tailor a crystal with great precision for a particular purpose, and when he is able to predict with assurance the electrical behavior of a novel compound before preparation, he will trace his technology back to research now in progress at scores of laboratories devoted to the theoretical and experimental analyses of electronic solid state materials.

The Solid State Sciences Laboratory conducts a number of analytical and theoretical studies which are broadening the understanding of basic semiconductor and magnetic mechanisms. This research covers the theory of

Microwave spectroscopy (nuclear magnetic resonance) is extensively used in unraveling the mysteries of the internal structure of matter.

crystalline solids, electrical structure of metals and semiconductors, quantum mechanics, cohesive energy in solids, ionic and molecular crystals, the work function and surface barriers, and the magnetic, optical, thermal, and structural properties of solids.

Many analytical tools are used — x-ray, spectrography, Mossbauer effect analysis, magnetic resonance, and so on. One by-product of the use of the Mossbauer effect in crystal analysis by the Laboratory was a new formulation of Mossbauer effect theory. Starting from one of the basic laws of quantum mechanics dealing with multiplication of probability amplitudes, an expression for the Mossbauer coefficient was derived which appears to be more simple and direct than the previous expressions.

ATOMIC THREE-BODY PROBLEM: An improved method for dealing with one of the most challenging of all mathematical problems — the three-body problem — was devised by a Laboratory scientist. The work has been widely recognized as a fundamental contribution to mathematics, with strong implications to crystal analysis. The problem is that of describing mathematically how three bodies, each exerting a force on the other two which depends on the relative distance between them, behave with respect to each other. Although the more familiar instances in which this problem crops up — such as the behavior of asteroids under the gravitational influence of both Jupiter and the sun — lie in the realm of celestial mechanics, the three bodies involved do not necessarily have to be celestial. They may be atomic or subatomic particles, and the forces between them need not be gravitational. They may be electromagnetic or nuclear. It is wth the latter type of three-body problem that the method deals.

Since modern atomic theory and quantum mechanics are inextricably related, the behavior of three interacting atomic or subatomic particles becomes a quantum-mechanical three-body problem. At first glance it might seem that such a problem would be more difficult than the three-body problem of classical or Newtonian physics, but this is not the case. Quantum theory allows particles to have only certain discrete energies, and this condition imposes a limitation on their behavior. Actually, if all their possible energy states are considered, the problem becomes identical with the three-body problem of classical physics. But if particles in only a single energy state are considered, the problem is greatly simplified, although still complex.

Essentially, the treatment consists in writing the Schroedinger wave equation in such a way that through a series of transformations and approximations it can be put into a form similar to that of the two-body problem. Two-body problems are relatively easy to solve.

One distant goal of the three-body study is the prediction of the physical properties of new materials and alloys. This actually involves a many-body problem, the many bodies being, say, the atoms in a crystal lattice. The three-body problem is only one special case of this many-body problem.

LATTICE DYNAMICS: Over the past several years the Laboratory has devoted considerable theoretical attention to lattice vibrational spectra. From these studies, a new concept, which has been termed the "centro-frequency of lattice vibration spectra" has been derived. It characterizes the entire vibrational (infrared) spectrum of a solid. The same concept has been recently found to apply to the elastic (acoustic) spectrum of a solid, and

Lattice structures have been studied for the past several years as a means for obtaining knowledge of the fundamental forces that hold matter in the solid state.

even to the spectrum of the black body radiation.

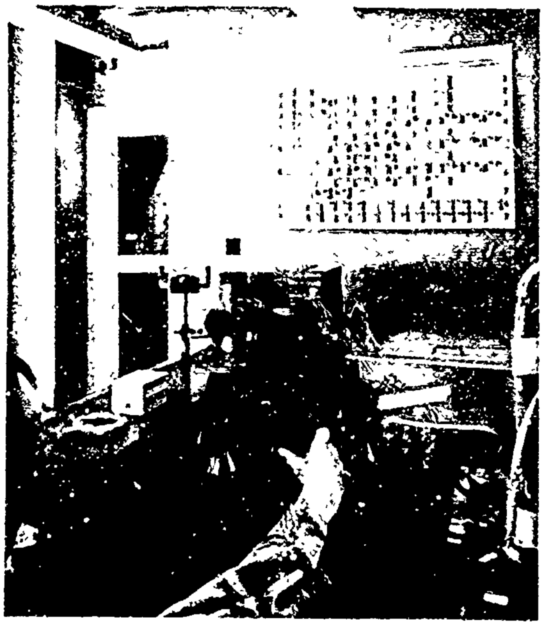
The assumption underlying this field of inquiry is that many physical properties of solid materials should be readily detectable and predictable with a good degree of accuracy on the basis of the lattice vibrational spectrum of these materials. But to establish relations between the vibrational spectrum of a substance and its physical properties is a task of monumental proportions. The goal may ultimately prove to be unattainable. Nevertheless, the study has already uncovered new and unsuspected relationships of interest to scientists in many disciplines.

The spectrum of any material presents a very complex picture. It varies greatly, depending on how it is measured. Spectra obtained of a given material by IR reflection, IR absorption, Raman scattering, UV spectroscopy, and neutron scattering are all quite different. None, taken by itself, can be used to derive more than a few characteristics of a material. Nor has a convenient and valid mathematical means been found to relate the spectra for application to the investigation of solids.

The "centro-frequency" concept, developed at AFCRL several years ago, provides a basis for the mathematical exploration of the physical properties of the material. (The centro-frequency can be considered as the center of mass of an IR absorption spectrum for any material. It is quite literally that point on an IR absorption plot where the area bounded by the trace on one side equals the area bounded on the other.)

The centro-frequency concept has proved to be, based on experimental measurements over the past several years, an extremely realistic, versatile and useful representation of the lattice vibration spectra. It has been applied with interesting results to a host of problems. Among these are: lattice cohesive energies, zero-point energy, compressibility, change of compressibility with pressure and temperature, thermal expansion, exponent of repulsion, characteristic temperature, hardness, and binding forces of solids.

OPTICAL PROPERTIES OF CRYSTALS: The optical properties of a crystal are characterized by two fundamental constants, the refractive index and the extinction coefficient. Knowledge of these constants provides information on the band structure, impurity levels, and lattice vibrations of the crystals. During the period, the Laboratory made optical measurements on many semiconducting materials (diamond, magnesium stannide, silicon carbide, magnesium germanide, boron, silicon)



Irradiation of crystals can break down the lattice bonds within the crystals and can thus alter electrical properties. Here a scientist is examining radiation damage to a crystal irradiated in the Van de Graaff generator facility.

at frequencies from the ultraviolet to the far infrared.

Instrumentation was developed to measure very small samples over a range of temperatures extending from 15 to 400 degrees K. This equipment included an evacuated dewar, selective radiation filters, and focusing arrangements for imaging the spectrometer beam at sample and detector positions. With this equipment both reflection and transmission measurements can be made without changing the sample position. From these two independent measurements, the optical constants at the particular frequency can be determined.

If optical measurements are extended over the entire electromagnetic frequency spectrum, the properties of the material can be evaluated from a single experiment. The usual procedure is to investigate the reflectivity and calculate the refractive indices and extinction coefficients by applications of either the Kramers-Kronig integral relations or classical oscillator theory. Done manually, this task requires unreasonable time and patience. With high speed digital computers, the task is reduced to reasonable proportions. Both the Kramers-Kronig and dispersion analysis were machine programmed and subsequently applied to the investigation of infrared lattice vibration spectra of various materials.

Magnesium stannide absorption spectra in the various regions have characteristics attributed to free carriers, valence to conduction band transitions, transitions within the conduction band, and lattice vibrations. The reflectivity of the fundamental lattice vibration region has been analyzed, and the following obtained: frequencies, strengths, and linewidths of the infrared active models, high and low frequency dielectric constants, and the refractive index and extinction coefficient as a function of wavelength.

The optical and acoustical branches of the lattice vibration spectra at the Brillouin zone boundary can be characterized in terms of two longitudinal and two transverse phonon energies. In polar crystals, a photon interacting with the crystal lattice will emit or absorb the zone boundary phonons. These phonons can be observed in transmission in terms of summation and difference bands. Two and three phonon combination bands and their temperature dependence have been observed in Mg_2Sn.

The effective mass of a semiconductor can be determined from the contribution of free carriers to the electric susceptibility. The effective mass can be calculated for an intrinsic sample from the rise of reflectivity at longer wavelengths. The shift of the free-carrier plasma frequency towards shorter wavelengths will indicate the effective mass variation with carrier concentration. These effects have been observed for compounds of the II-IV series.

IONS AND ANIONS: In analyzing the properties of electronic materials, the roles of positive and negative ions — the ions and anions — are of special interest since these are the active elements. For example, in the ruby crystal, it is the positive chromium ion (Cr^{+3}) in the host aluminum oxide (Al_2O_3) lattice that makes the ruby laser possible.

Although environmental influences on the electronic states of positive metal ions have been extensively studied, there has not been a corresponding attention given to the associated negatively charged ions (anions). The Laboratory, during the reporting period, undertook a detailed study of these anions. The investigation required that a series of compounds involving one type of metal anion and a large number of metal ion types be prepared.

The anion chosen was the acetylacetonate anion with a negative charge of one and a possessor of two sites which could interact with metal ions. The ultraviolet spectra of a series of 40 compounds, each involving this anion with a different metal ion, were obtained. Because of the variety in characteristics of the metal ions, several relations were established, including the influence of the character of the metal ion-anion bonds, the charge and radius of the associated metal ion, and the geometry of the associated ion on the spectrum of the anion.

The present investigation has shown that the electronic states of an anion are under certain circumstances influenced by the metal ion with which it is associated, and that a pattern of interrelationship of the spectral, physical, and chemical properties exists. This has been demonstrated for a single anion, but it is uncertain whether this is a general situation. To try to clarify this point, the spectra of two other anions are being investigated. Nevertheless, in light of the Laboratory's findings, conclusions based on previous studies of the spectra involving reactive solvents or contaminants must be carefully reconsidered.

MAGNETO-CRYSTALLINE ANISOTROPY: When the experimenter sets out to determine the anisotropy (ease of magnetization as a function of crystal orientation) properties of a ferrimagnetic crystal, he measures the changes in the external magnetic field required to obtain strongest magnetic resonance at different crystal orientations. He attempts to keep the temperature and the energizing microwave frequency constant. Essentially, this method of analysis has three limitations: the crystalline axes must be aligned with extreme precision, changes in crystal temperature may invalidate results, and the experimental data are difficult to interpret.

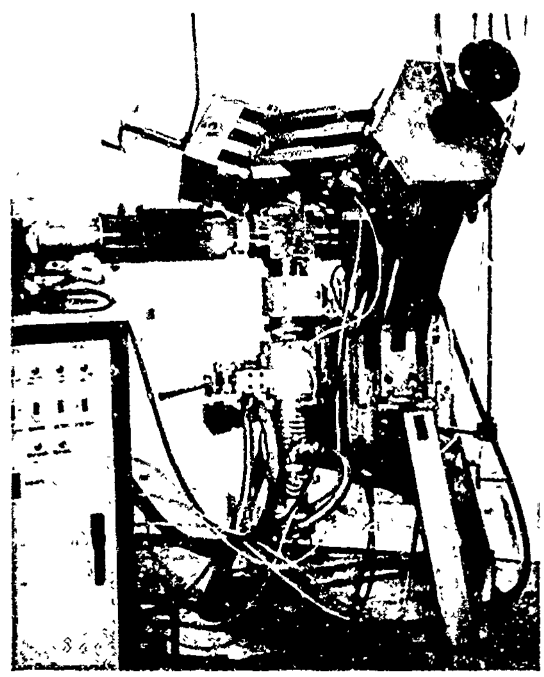
Laboratory scientists have obtained a clearer insight into magnetic resonance in ferrimagnetic crystals. The insight was found in the development of a new resonance equation, an equation arrived at following rather lengthy algebraic procedure. This has resulted in procedures for the utilization of ferrimagnetic materials which do not depend on extremely precise crystal alignment or careful temperature control.

To understand the nature of the discovery, it is necessary to briefly consider magnetic resonance phenomena. At magnetic resonance, the magnetization vector precesses about an equilibrium. The precession frequency of the magnetic vector is basic to the novel procedures formulated by the Laboratory. The precession frequency depends on the torques which the magnetic vector experiences both from the external magnetic field and from variations of the anisotropy energy with position in the lattice. Heretofore, all practical application was based on the belief that at only one crystal orientation — one "singular" direction — was the precessional frequency uninfluenced by anisotropy energy and variation with temperature. Ideal crystal orientation was required to guarantee elimination of the temperature effect on magnetic resonance. The AFCRL studies led to the evidence that not one but a continuum of "singular" directions exist. What is meant by "singular" directions in this case are the crystalline orientations at which the precessional motion is not affected by the anisotropy.

Because anisotropy constants are highly temperature-dependent, a slight change in temperature would, under previous procedures, force a reorientation of the crystal to obtain sharpest resonance. But using resonance equations and procedures based on the newly discovered continuum of "singular" directions, temperature becomes a less important consideration.

Experiments have proved the effectiveness of the new measurement approach. In certain planes, deviations up to about ten degrees from the ideal position of the crystal did not markedly affect the resonance field over a temperature range of approximately 30 degrees Kelvin above and below ambient.

ANALYSIS OF DIAMOND: Diamond, potentially a high temperature semiconductor material, has been analyzed in detail by several techniques. One technique that has proved especially fruitful is the detection of trace impurities of paramagnetic materials in the host lattice by measuring paramagnetic resonance. In these studies, the nature of the impurity in atoms and the structure of the impurity site can be deduced from the intensities of the resonance lines and the magnitude of the magnetic field required for their appearance. Paramagnetic resonance techniques have been applied to the evaluation of impurities in several semiconductors, altho 'h diamond has received primary at' 'n.

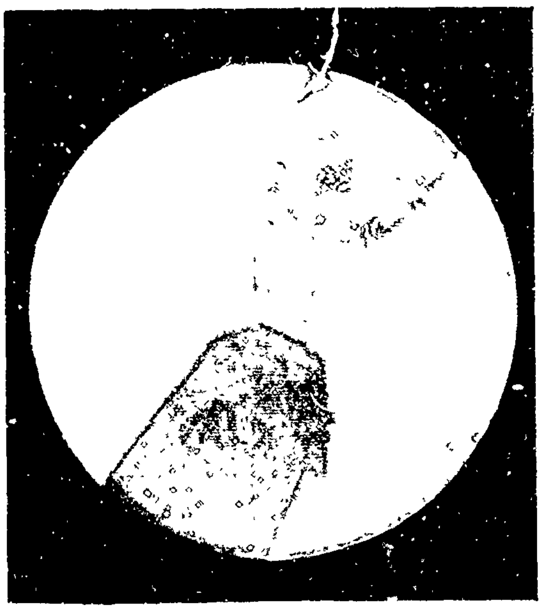


Installed during the reporting period was a new high pressure apparatus which permits the scientist to view, by means of the associated x-ray analysis equipment, the transition of materials from their normal phase to the high pressure phases.

DEVICE RESEARCH

Device research at AFCRL is currently concentrated on semiconductors. Although this work is directed towards new and improved devices for use in Air Force operational hardware, some of it is quite basic and exploratory. Included in the more basic studies are investigations of the physical constraints to optimum size and performance of devices. Logic networks taking into account these physical constraints are then investigated.

The device research program during the reporting period was concentrated in six areas: 1) new silicon transistor design, 2) improvement of device fabrication techniques, 3) III-V semiconductor lasers, 4) II-VI semiconductor diode light emitters, 5) heterojunctions, and 6) fundamental properties of degenerate semiconductors. The first



Light emissions are clearly visible at the junction of this gallium arsenide laser.

four are easily categorized as device oriented even though there are a number of very fundamental problems inherent in them. Areas 5 and 6 are not directly aimed at specific devices but are of a more general nature, having potential application in a number of different device areas.

CURRENT TRANSPORT ANALYSIS: Properties of materials that are difficult to measure in bulk samples may be observed more readily in p-n junctions. Within the past year, detailed studies of p-n junctions in degenerate materials have been conducted in order to find out more information about these materials. It should be noted that degenerate materials, unlike the relatively pure semiconductors of transistor technology, are highly disordered due to their large number of impurities. Conventional semiconductor measurements are greatly compromised by a high proportion of free carriers. It was therefore necessary to develop new methods of transport analysis. Among these methods, the measurement of static volt-ampere characteristics proved most useful.

Arsenic doped degenerate germanium was an especially interesting study sample because of the presence of both direct and phonon assisted tunneling components in narrow p-n junctions. Very accurate measurements of the volt-ampere characteristic were made followed by machine computation to extract the natural fine structure inherent in the conduction process. The technique proved very successful. Some of the observed characteristics were:

1) The position of the secondary minimum in the conduction band of germanium was determined to be 154 $\pm$ 5 MV above the 111 minima, regardless of impurity density. In contrast to previous measurements using the volt-ampere characteristic, this value is in excellent agreement with the results of optical measurements of relatively pure germanium.

2) Sharp phonon structure was observed in arsenic doped samples. The structure occurred at the same energies as those reported for antimony doped material. (Other measurement techniques have difficulty in resolving the phonon structure.)

3) The presence of random fluctuations in impurity densities at high impurity concentration leads to uncertainty in the band model for heavily doped materials. Information sufficient to determine the resulting disorder in the band edge has been observed and is presently being analyzed.

METAL-SEMICONDUCTOR JUNCTIONS: Conventional p-n junction transistors are approaching their theoretical limitations in performance. But in considering junctions other than the regular p-n junctions, one may breech the calculated ceiling imposed on the transistor. Several unconventional junctions are being studied. One of these are Schottky junctions — metal-semiconductor junctions.

Current transport process across a Schottky junction is one in which the majority carriers in the semiconductor are injected over the barrier into the metal. These carriers appear in the metal as hot carriers because they possess more kinetic energy than the average thermal carriers in the metal. These hot carriers, being distinct, can be controlled in a selective manner. This means that a potential barrier of height slightly less than the kinetic energy of the hot carriers will not stop them but will stop most of the thermal electrons. The problem is that these hot carriers lose energy through collision with other carriers or the crystal lattice and relax to thermal equilibrium. The hot carriers that suffer energy loss will not be able to surmount the collector barrier.

If the hot carriers possess a sufficiently long mean life path (an interval in which the carrier suffers no energy loss), and a thin metal base is provided, then a sizable portion of the injected carriers can be collected. This is the principle of a hot electron metal base triode is under study by the Laboratory. Theoretical calculations have shown that this device will have the potential of a higher gain-bandwidth than the theoretical value for transistors.

Experiments are focused on current flow mechanisms and the barrier height. Different kinds of Schottky junctions are being tested to learn something of the lifetimes of hot carriers as a function of energy in different metals.

The junctions that were being studied are metal-Si junctions. Photocurrent yield versus light frequency and capacitance-bias voltage measurements are used to get the barrier heights. Pulse switching experiments are used to ascertain the current flow mechanism. Various ways of fabricating the triode are also being investigated.

SEMICONDUCTOR - SEMICONDUCTOR JUNCTIONS: A heterojunction device is one in which a junction is formed between two different semiconductor materials. Using the same theoretical analysis for heterojunctions used for p-n junctions made in the same material, more latitude in device design is permitted. But the heterojunction must be of similar quality as a regular p-n junction and achieving this is not easy. Crystalline mismatch, interdiffusion, solid solubility, dangling bond, and so on, are factors to be minimized. Most of the Laboratory research on heterojunctions is devoted to fabricating an abrupt junction with a minimum of interfacial states between germanium and gallium arsenide.

NEW FIELD EFFECT DEVICE: Majority carrier devices promise higher radiation resistance, larger temperature range of operation and less stringent material requirements. Research on reverse biased, junction-type field effect and insulated gate field effect devices has led to the development of a small current amplifying device — designated SCAD — which has better current amplifying capabilities than normal bipolar transistors.

The small current amplifier, as pictured in the accompanying illustration, is a junction-type field effect device that

The etched cross section of AFCRL's new silicon field effect current amplifying device (SCAD) is shown. The gap between the vertical elements is only one micron across.

operates with its gates forward biased. At zero gate voltage the channel is totally closed by the natural depletion regions surrounding any p-n junction. When the gates become forward biased by a small current signal the depletion layers recede and a considerably amplified current passes from source to drain through the now opened channel. The extended volcano geometry of the channel, the cross-section of which is revealed by carefully staining the P areas is especially advantageous since the actual pinch off region is very short. In this manner the "on" state exhibits a low resistance while the "off" state has a very high resistance. Direct current amplification factors over a hundred for currents as low as 10^{-10} amperes have been obtained. These devices have been tested for small current amplification at room temperatures as well as at liquid nitrogen temperature.

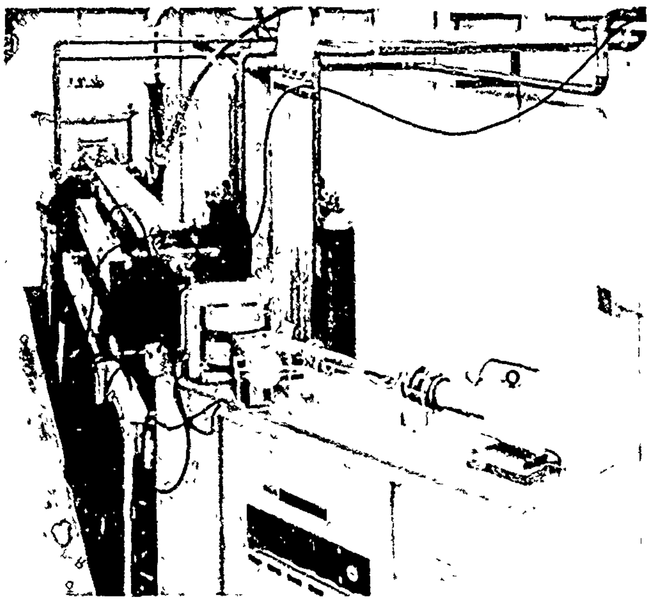
A major feature is their high resistance to radiation. Tests have shown that they are less subject to permanent damage from steady-state radiation than normal bipolar devices.

LIGHT EMITTING DIODES: AFCRL's program on electron injection electroluminescence in the II-VI compounds extends back several years. These high gap semiconductors had proven their ability to both photoluminescence and electroluminescence. Efforts are concentrated on improved efficiencies. The approach is through the injection of carriers to achieve subsequent recombination with attendant radiation. This work is carried out both in-house and under contract.

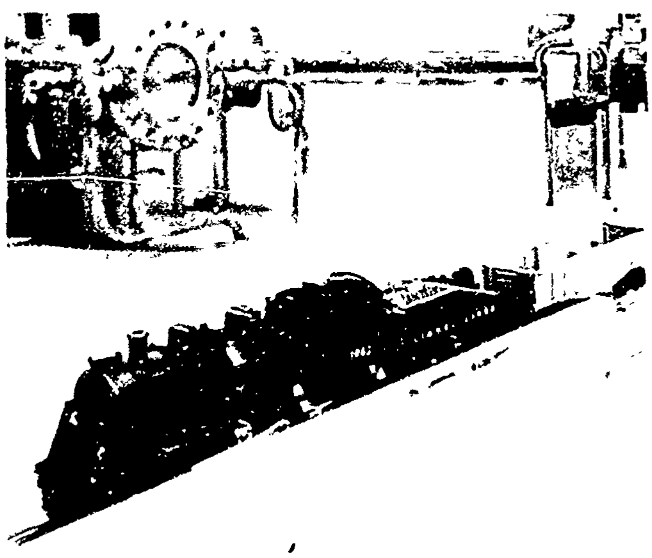
Carrier injection requires a p-n junction; junctions suitable for injection have been very difficult to achieve. This problem has been partly solved and injection electroluminescence has been obtained in a number of II-IV's. Efficiencies, initially low, have been improved. Recently, General Electric of Schenectady, under AFCRL contract, succeeded in making an electroluminescent diode with an external efficiency of 2.5 percent, compared to previous efficiencies of one percent.

This was accomplished by reasoning that if ZnSe could be made n type and ZnTe could be made p type, perhaps a mixed crystal would be amphoteric. A 40-60 mixed crystal was grown p type which successfully accepted an aluminum diffusion to form a p-n junction. This junction was made to glow at liquid nitrogen temperature with as little as eight microamps and glowed visibly in a lighted room at 30 microamps. Current work is aimed at obtaining higher efficiencies. Theoretically, efficiencies of 90 percent are possible.

In addition to the above program, research is continuing on gallium arsenide diode lasers. These studies are focused on the mode structure and the intensities of the mode as a function of injection current, pulse length and



A 21 mev linear accelerator was placed in operation at AFCRL in April 1965. To transport the samples to be irradiated before the irradiating nozzle a toy train is used.



individual diode characteristics such as diode size and the nature of the cavity surfaces. GaAs is well suited for studies of light emission. Further understanding of the mechanism involved in mode and energy shifts may indicate methods of exaggerating the effects in order to make them useful for F. M. communications.

RADIATION EFFECTS ON MATERIALS

Techniques for predicting, controlling and lessening the effects of radiation on electronic systems unavoidably exposed to radiation —— whether in space or in the ground environment — are of major Air Force interest. These radiation environments range from those generated by nuclear weapons and nuclear power sources to those that have been, or will be, encountered by satellite and rocket probes in space — Van Allen belts, solar proton showers, and cosmic rays. Malfunctions in many satellites have been attributed to radiation damage. The Laboratory's research program devoted to radiation effects is directed towards the development of methods for minimizing and predicting undesirable effects on materials used in solid state devices.

THE AFCRL RADIATION COMPLEX: The accompanying table shows the major instrumentation of the AFCRL radiation complex. Installation of an L-band microwave high energy electron linear accelerator was completed in April of 1965. The nominal energy of this machine is 12 Mev, but it is capable of accelerating electrons to energies ranging from 3 to 21 Mev. It furnishes intense pulses of electrons with pulse widths ranging from ten nanoseconds to 4.5 microseconds. With appropriate targets, x-rays, neutrons, and positrons, can be produced. Equipment and techniques for characterizing the properties of the primary electron beam and its associated bremsstrahlung have been designed and fabricated. These include

PERFORMANCE CHARACTERISTICS OF AFCRL RADIATION SOURCES

RADIATION SOURCE	TYPES OF RADIATION	ENERGY RANGE	BEAM CURRENT, DOSE RATE OR FLUX
Dynamitron	Electrons	0.25–1.5 Mev	10 ma
	X-Rays	0.25–1.5 Mev	2 x 10^7 r/hr
Van de Graaff	Electrons	1.0–3.0 Mev	[illegible] ma
	X-Rays	1.0–3.0 Mev	[illegible] 10^7 r/hr
	Protons, Deuterons and other positive particles	1.0–3.0 Mev	450 μa
	Neutrons	Thermal to 20 Mev	$\approx 10^8$ n/cm^2–sec
Linac	Electrons	3.0–21.0 Mev	2 amps (in a pulse)
	X-Rays	3.0–21.0 Mev	10^7 r/sec (in a pulse)
	Neutrons	$\approx$ 1.5 Mev	10^{13} n/cm^2–sec (in a pulse)
Cobalt-60	Gamma Rays	1.2 Mev	5 x 10^5 r/hr

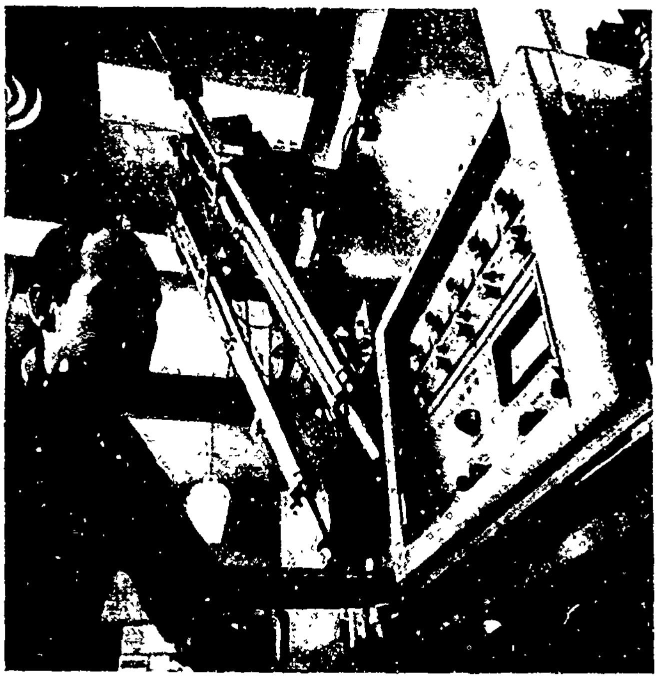
a secondary emission monitor, a high intensity ionization chamber, and survey instrumentation for safety monitoring.

Other research equipments include a 3 Mev Van de Graaff generator, a Dynamitron, and a Cobalt-60 source and associated chamber. During the period the maximum energy of the Dynamitron electron accelerator was increased from 1.2 to 1.5 Mev.

RADIATION DAMAGE IN CRYSTALS: Explorers XV and XVI, UK-1, TRAAC, Transit IVB and Telstar I have all fallen prey to radiation damage. The lattice structure of a crystal is damaged when energy is transferred from nuclear radiations to an atom. If the transferred energy exceeds a certain critical value, the atom will be displaced from its normal lattice position. The amount of energy required to eject an atom from its lattice site is the so-called threshold energy for atomic displacement. The parameter of primary interest is the "effective" threshold which is used to calculate the number of atoms displaced by bombarding radiations. The present effort is directed toward the improvement of methods for predicting this important parameter. It is presently known for only about a dozen elements and compounds.

The effective threshold is determined experimentally by measuring the relative cross-section for damage production as a function of bombarding electron energy. Since accurate knowledge of electron beam current and energy is essential in experiments of this type, considerable attention was given to the development of suitable instrumentation and techniques for the control of these beam parameters. It is necessary to conduct these experiments at low temperatures (approximately ten degrees K) in most materials in order to avoid defect interaction which could lead to a nonlinear accumulation of damage and difficulties in interpretation. Careful experiments of this type have been carried out on platinum as a representation of the high atomic number elements.

An unexpected result was found in the energy region where multiple displacements take place. In this energy region, the damage rate was greatly



Irradiation level outside AFCRL's kilocurie cobalt 60 cell (in background) is being monitored. Associated with the cobalt 60 source is a 3 mev Van de Graaff generator and a 1 mev Dynamitron.

accelerated. The reason for this was found in the fact that some of the primary recoil atoms have sufficient energy to produce secondary displacements. This secondary effect will be studied in future experiments.

To interpret the experimental damage rates as a function of electron beam energy, it is necessary to have accurate values of the electron scattering cross-section. For high atomic number elements the exact form of the Mott-Rutherford cross-section formula must be used. Accordingly, a computer program was written for any combination of atomic number and bombarding electron energy. The input includes the energy in Mev, the threshold in ev, the atomic number, and the mass of each isotope with its percent abundance.

Calculations were also carried out to evaluate probability displacement functions that differ from the simple step function normally assumed for relative cross-section calculations.

It was found that the details of the function were unimportant but that the rate at which the function was allowed to rise from zero had a marked influence on the calculated cross-sections. For the region where multiple displacements are important it is necessary to estimate the average number of displacements per primary recoil. A rigorous comparison of the available theoretical models has been initiated.

In addition to studies of the mechanisms involved in the displacement of atoms in crystals, attention is also being given to the nature and properties of the defects that result from such displacement. Germanium and silicon are of particular interest because of their availability in a high state of chemical purity and physical perfection, and their wide application. To understand the radiation induced property changes in these materials, it is desirable to identify the primary defects introduced as a function of the radiation, the defect complexes that result from the interaction of the primary defects with defects present prior to the irradiation, and the factors controlling the interaction. Since available experimental data indicate that the primary defects in germanium and silicon are mobile at very low temperatures, cryogenic equipment for conducting irradiation experiments below ten degrees K is being assembled. Equipments have been assembled for studying such properties as the carrier concentration, mobility, and lifetime.

IRRADIATION SERVICES: The radiation program of the Laboratory is a two-part one. Besides research on the mechanism of radiation damage, the radiation facility is used to provide services for other Laboratory elements, for AFCRL contractors, and for other agencies of the Government. Specific investigations of a service nature conducted during the period are itemized below:

1) Gamma irradiations of a prototype device.

2) The photovoltaic effect associated with electron induced lifetime gradients in germanium and silicon.

3) Determination of energy levels in gamma irradiated germanium.

4) Suppression of dislocation attenuation with gamma rays in ultrasonic studies of copper.

5) The development of neutron targets for transmission studies.

6) Determination of the gamma radiation stability of rocket propellants.

7) Laser pumping using energetic electrons.

8) The stability of adhesives used in satellite structures.

9) The development of a dosimeter for weapons measurements.

10) Effects of gamma irradiation on electronic circuits.

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X Aerospace Instrumentation Laboratory

The program of the Aerospace Instrumentation Laboratory — when viewed against the more basic research oriented programs of those Laboratories discussed in the foregoing chapters of this report — extends well into the field of development and engineering. Much of its total effort goes into the support of other AFCRL Laboratories, outside Air Force agencies, NASA, and universities working under Air Force contracts.

The program of this Laboratory has three rather discrete aspects: 1) the development of improved research vehicles — balloons, rockets and satellites — for transporting scientific instrument packages into the upper atmosphere and beyond, 2) the generation, analysis, compilation and dissemination of climatic and atmospheric data essential to designers and operators of aircraft, rockets, missiles and satellites, and 3) the development of meteorological equipments and systems for the Air Weather Service and other Air Force agencies.

Most of AFCRL's rocket and satellite probe experiments and all of its balloon flights come under the general purview of this Laboratory. The Laboratory provides scientists in other Laboratories with guidance in the design and fabrication of experiments and integrates their experiments into the overall flight packages. This responsibility includes arrangements for the launching of AFCRL rocket probes and satellites and for the telemetering and decommutating of data. It also includes the launching of balloons for AFCRL and other agencies at the Holloman and Chico sites. In this sense, the Laboratory is largely responsible for the management of the AFCRL research vehicle program.

During the July 1963 - June 1965 reporting period, the Laboratory developed, or funded the development of, several new balloon and rocket vehicles. Progress in balloon technology was particularly notable, resulting in a new generation of lighter, stronger, and less expensive vehicles for carrying heavy payloads to altitudes of 30-50 km. A new sounding rocket with increased payload capacity was introduced, and a less expensive meteorological rocket was developed. Hundreds of balloon and rocket flights were made during the period. A listing of all rockets and satellites which carried AFCRL experiments during the period is contained in Appendix C. The list shows the types of vehicles used, launch site, the nature of the experiments carried aboard, and the success or failure of the flight.

RESEARCH PROBE PROGRAM

The Aerospace Instrumentation Laboratory manages the AFCRL research rocket probe program. This means that scientists and engineers of this Laboratory work closely with other AFCRL Laboratories who are large users of probe vehicles. The Laboratory fires about 50 large sounding rockets a year and about an equal number of smaller meteorological rockets, making AFCRL one of the world's largest users of these vehicles.

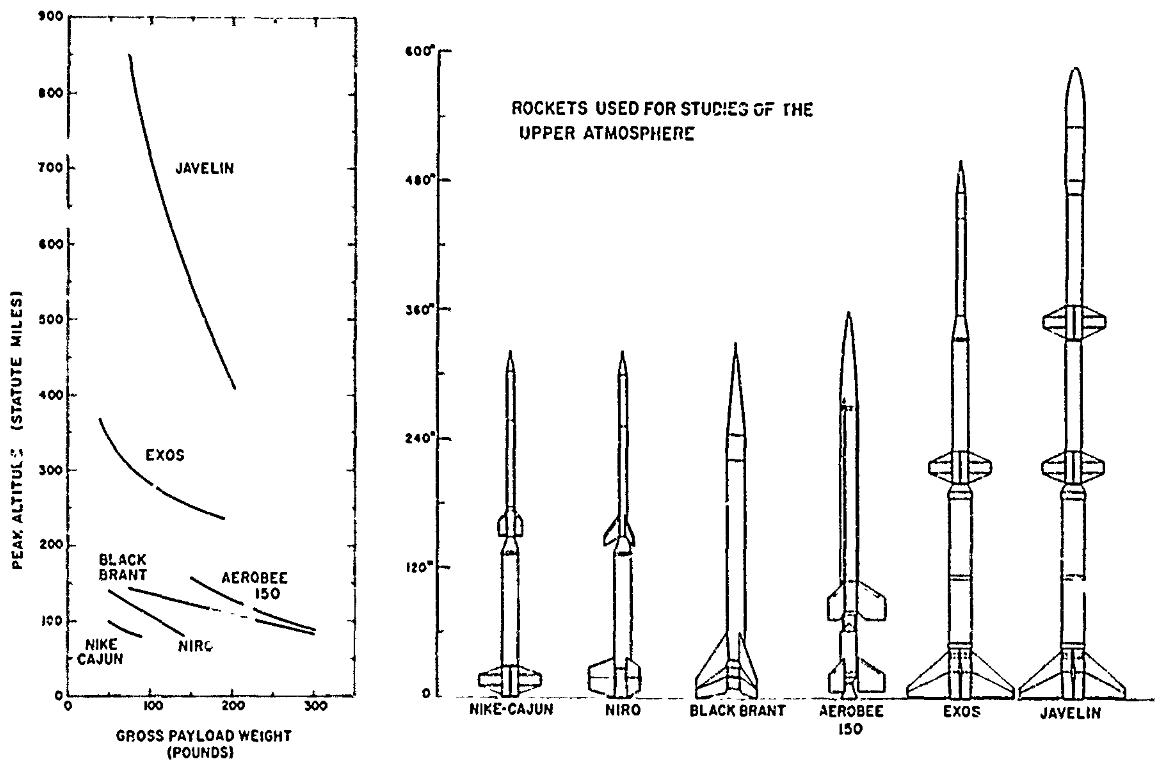
Aerobees, Nike-Cajuns, the Trailblazer-2, the Astrobee 200, the Exos, the Astrobee 1500, the ARCAS, the Black Brandt and the Blue Scout, Jr. are among AFCRL's rather extensive inventory of sounding rockets. These rockets have carried experiments aloft from Cape Kennedy, the White Sands Missile Range, Eglin Gulf Test Range, Ft. Churchill, Canada, Wallops Island, Virginia, the Kronogard Range in Sweden, and from the decks of various ships.

The experiments carried aloft during these flights dealt with airglow phenomena, the nature and intensity of solar ultraviolet radiation and its effect on the upper atmosphere, lunar X-ray observations, ionospheric properties, geomagnetism, EM wave propagation, and noctilucent clouds — in short, with most areas of environmental research. This research is aimed at uncovering new knowledge of the physical properties of the region between 40 and 16,000 km above the earth — the environment in which future Air Force vehicles will operate.

Management of the AFCRL rocket and satellite program has many facets including vehicle selection, range scheduling, structural design, payload integration and fabrication and systems for data transmission and decoding. Laboratory personnel plan with each scientist the overall data flow from basic sensor to final report.

BLUE SCOUT FLIGHTS: Since 1961, the Laboratory has used Blue Scout vehicles to orbit satellites and carry probes into deep space. The guided version of this four-stage rocket can place up to 200 pounds in low earth orbit, while the unguided version, the SLV (Standard Launch Vehicle)-1 B formerly the Blue Scout, Jr., can carry much smaller payloads over ballistic trajectories with peak altitudes of several earth radii.

During the present report period, five deep space probes were carried aloft by SLV-1 B's. Three of these flights

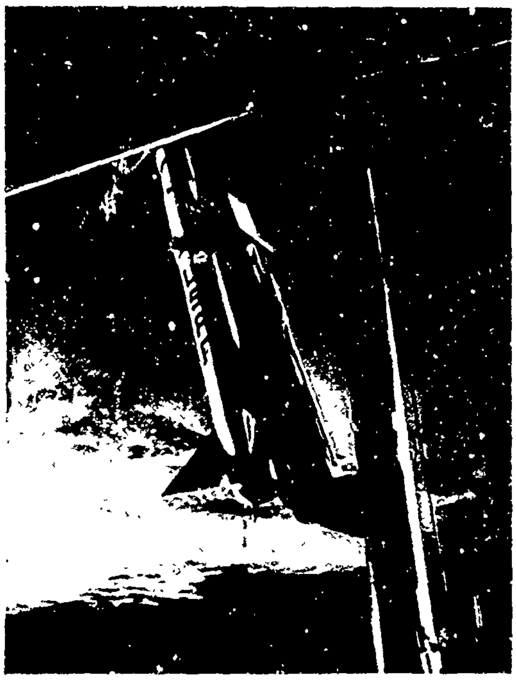


Left side of chart displays payload height curves for several of the vehicle configurations (shown at right) which are used in AFCRL's research probe program.

were successful. The first, launched in July 1963, is described in the previous report. It reached an altitude of 12,000 km, believed to be an Air Force record for deep space probes at the time, and all aspects of the flight were successful. Its instrumentation was designed to measure electrical structures along its trajectory. The two other successful shots, launched from Cape Kennedy in March and May of 1965, carried instruments to measure cosmic radiation, and reached heights of 16,000 km.

The OV-3 series of satellites, to begin in January 1966, will use Blue Scout boosters. The Laboratory is in charge of the entire series of six OV-3 satellite launches scheduled to take place during the subsequent 18-month period. Two of these are being designed, integrated, and tested within the Laboratory, while the remaining four are being provided by a contractor under direction of the Laboratory. AFCRL will instrument four of the six satellites completely. The other two will be used to carry out programs for the Air Force Weapons Laboratory and the Space Systems Division, but will be supported by AFCRL. The four AFCRL OV-3 satellites will be fired into elliptical polar orbits from Vandenberg AFB, California, and will carry sensors for sampling the space environment.

VEHICLE SYSTEMS: Since the launch, in 1946, of the first V-2 carrying an AFCRL payload, AFCRL has made many contributions to sounding rocket technology. These contributions include the development of better vehicles, the improvement of range safety, and preflight testing procedures to insure payload performance during flight.



The four-stage Blue Scout rocket is used by AFCRL scientists to carry instruments into the earth's radiation belts.

A two stage rocket, called Niro (Nike and Iroquois), is destined to replace the Nike-Cajun and Nike-Apache as the workhorse vehicle for studies in the ionosphere. This rocket was first flown in November 1964. The advantages of the Niro over preceding Nike-boosted sounding rockets are many:

1) Sharp cut-off of propulsion to prevent combustion products from mixing with the atmosphere after burnout and contaminating samples taken during the flight.

2) Better control of combustion, thus decreasing vibration of the payload compartment.

3) Better fin design to decrease rolling and tumbling, and for easier preflight adjustment.

4) A thirty percent increase in useful payload cross section to ease design requirements for flight packages. In addition, nominal payload capability of the Niro is double that of the Nike-Cajun (100 vs. 50 pounds to 150 km).

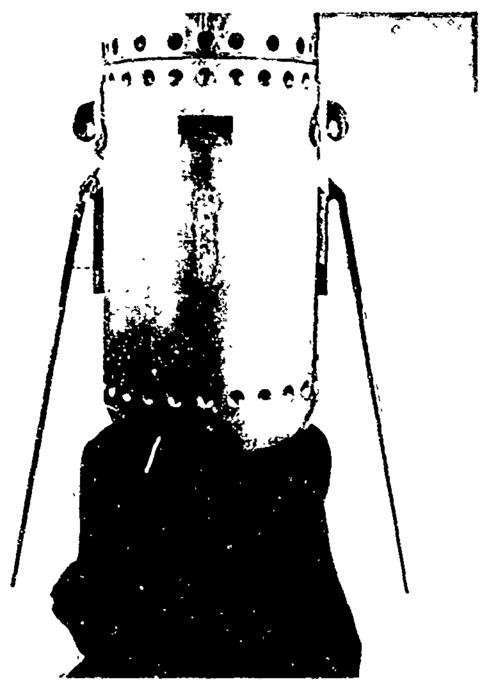
Following the first successful test flight of the Niro in November 1964, two more Niros have been successfully flown to date. The first of the two flights, a further test of the vehicle system, was launched from Eglin on 12 April 1965, and carried a payload of 125 pounds to 90 miles. The next flight, the first use of the Niro for sounding the upper atmosphere, took place on 21 July 1965 from Eglin. A three-foot inflatable falling sphere was ejected from the rocket at apogee to measure atmospheric density between 140 and 95 km. The sphere contained the accelerometers to measure drag decelerations and telemetry equipment to relay the measurements to the ground.

The in-house preflight testing of payload packages was expanded. Pre-flight testing of each payload with a 4500-lb force shaker and a vertical balancing machine is expected to increase payload reliability. Several basic studies to establish engineering guides for payload design were undertaken. Design constraints included: reentry effects, forces and moments acting on rocket motors, elastic and resonating effects of forward facing nose cone antennas and spikes, roll rate discrepancy due to inertia lag, and post-burnout stability.

TELEMETRY TECHNIQUES: Effective telemetry is one of several essential links in the chain of requirements for a successful rocket or satellite experiment, and a primary link in the telemetry system is the antenna.

During the report period, a new telemetry antenna was developed that has a nearly omni-directional radiation pattern, an important characteristic for relaying data from unguided rockets, since such effects as tumbling can cause the aspect angle between the antenna and the ground to vary greatly. Another characteristic of the new antenna is its wide-band operation which eliminates tuning difficulties caused by conditions of high humidity. This feature is of considerable value for flights launched from on board a ship, or taking place in moist climates. The antenna was first flown on a series of Nike-Apaches launched at sea off the coast of South America in mid-March of 1965 to gather data on the earth's magnetic field and the electrical structures of the equatorial electrojet. (Noted in Chapters II and IV.) The antenna performed well and has now become standard operational equipment, having been used on the Niro-borne upper atmosphere density experiment that took place in June 1965 and the noctilucent cloud experiments (Chapter IV) launched from Ft. Churchill, Canada, during July 1965.

Several techniques for determining a rocket's trajectory through its telemetry system are being explored. These are of interest primarily where no radar or other tracking system is available. One such technique, using information telemetered from an accelerometer in the rocket, has been tried on several flights. When the telemetered trajectory data were reduced and compared with radar trajectory data, the agreement was within two to five percent. On several occasions at the Ft. Churchill Research Range, this technique has yielded the only trajectory information on the flight when the radar system failed.

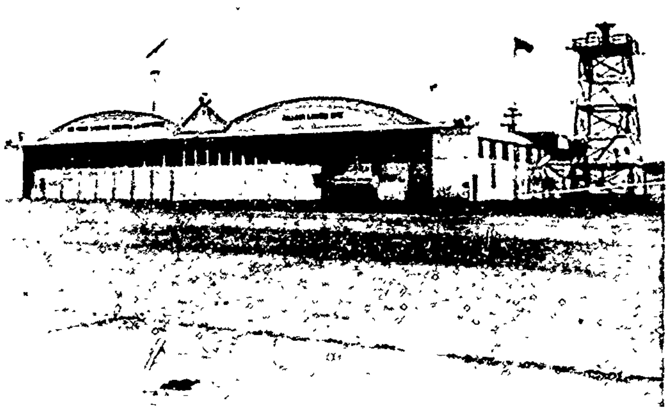


This newly developed antenna, mounted near the base of a nose cone, has a nearly omnidirectional radiation pattern, making it particularly effective for telemetering data from tumbling vehicles. It also has wideband characteristics which eliminate tuning difficulties caused by humidity.

BALLOON TECHNOLOGY

The Laboratory is the largest developer and user of balloons in the U. S. It annually launches almost three times as many balloons as sounding rockets — about 135. The Laboratory has primary responsibility for the Air Force's balloon program, a responsibility that includes both balloon development and ballooning techniques, and the support of AFCRL Laboratories and Air Force agencies making environment observations at altitudes between 30 and 50 km. An increasing number of applications are being found for large balloons both in high altitude research and in military operations. This increase is reflected in the growth of AFCRL's balloon program during the past two years.

During the July 1963 - June 1965 reporting period, the Laboratory launched 270 large research balloons, including one with a volume of 13.5 million cubic feet — the largest balloon ever flown. With this exception, balloon volumes ranged from about one million to 5.25 million cubic feet, and payloads averaged 1000 pounds, though many loads exceeded 2000 pounds. For these heavier payloads, balloons made of a dacron-reinforced mylar film, called scrim laminate, were used. Some 20 flights were performed with these scrim balloons. More than half of all flights were launched from AFCRL's balloon launch facility at Holloman AFB, New Mexico. Forty percent were launched from AFCRL's other launch site at Chico, California. The remainder were launched from shipboard or remote locations.



AFCRL's balloon launch facility at Chico, California, is shown here. Buildings house instrumentation laboratory, and launch preparation, flight control, and weather station facilities.

The Laboratory's key role in balloon activity is reflected in the response to the two symposia on scientific ballooning conducted by AFCRL in September 1963, and in October 1964. These symposia provided the first comprehensive coverage of balloon technology, and were attended by hundreds of engineers and scientists representing scores of organizations. The sponsorship of such symposia or an abbreviated workshop is now planned as an annual event.

BALLOON DEVELOPMENT: The goal of AFCRL's balloon development program is to produce more reliable balloons for carrying heavier payloads to higher altitudes. Closely tied to this goal is the effort to reduce the cost of balloon material and fabrication. During the period July 1963 - June 1965, the Laboratory made marked progress in developing lighter, stronger, and less expensive balloon materials. This progress has led to the threshold of a new generation of vehicles for probing the upper atmosphere.

Thin-film polyethylene balloons have been the workhorses of ballooning since their introduction in 1945. They meet most flight requirements, but the need to lift much heavier payloads to higher altitudes for longer time periods and the occasional need to launch in less than ideal weather have created requirements for balloons of greater structural strength.

Early in 1960, a new material, a laminate of woven dacron fiber and mylar film, was introduced into ballooning. This scrim was extremely attractive as a balloon material but the cost of balloons made of this material was too high for most scientific experimenters. As a consequence, the Laboratory undertook a program to reduce the cost of scrim balloons by studying materials and production methods. This led to a new technique for fabricating scrim balloon materials.

The new fabrication technique was made possible by the development, in-house, of a new device, called the "Flying Thread Loom," for generating grids of dacron thread which can then be fed directly into a machine that laminates them to the mylar film. This capability will eliminate several costly steps from balloon fabrication. However, the Flying Thread Loom's most important advantage is that it can be used to vary the weave of the dacron grid — that is, the angle between cross-threads — and the density of the threads. Thus, balloons can be made much lighter, since the pattern of reinforcing threads can be varied to put the most strength at those points where the greatest stress occurs. In this way, an optimum strength-to-weight ratio can be achieved, making balloon flights with heavy payloads to extreme altitudes possible for the first time. The first balloon made by this new technique was successfully launched from Holloman AFB on 21 May 1965, and the technique has been recommended to other balloon-using agencies.

In addition to reducing the cost and improving the design of dacron-mylar scrim balloons, Laboratory scientists developed a second reinforced balloon material during the report period. This new material, consisting of two layers of 0.14 mil polyethylene reinforced with a network of fine nylon filaments, has an extremely high strength-to-weight ratio. It has the tensile strength of 2 mil polyethylene while weighing less than 0.33 mil polyethylene.

A comparison of balloon size needed with each of the two polyethylene materials to carry a given payload to a given height best demonstrates the improved capabilities of the new fabric. To carry a 25-pound payload to 150,000 feet using 0.5 mil polyethylene would require a balloon volume of 6 million cubic feet with a fabric weight of 550 pounds, as against a volume of 1.5 million cubic feet and a weight of only 119 pounds with the new fabric.

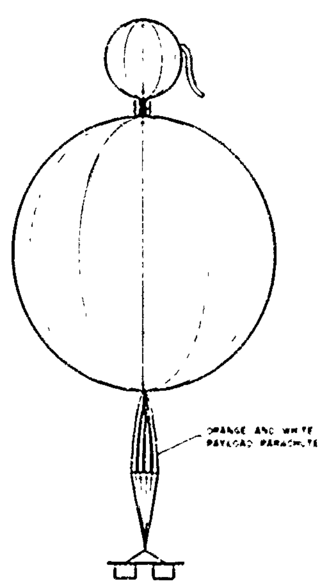
The pattern of dacron threads, laminated to mylar film to produce this strip of reinforced balloon material, was generated by a new device, the Flying Thread Loom, developed by AFCRL to reduce balloon manufacturing costs and increase the strength-to-weight ratio of balloon materials.

The first balloon made of this nylon-reinforced polyethylene was successfully launched from the Laboratory's Chico, California, facility on 4 December 1964. The balloon carried a 275-pound payload to an altitude of 95,000 feet. This flight was the first of several scheduled to test the new fabric.

For the normal range of payloads and altitudes, however, it is unlikely the new scrim balloon materials developed by the Laboratory will entirely replace unreinforced polyethylene. Even with maximum reduction in cost, reinforced materials will still be relatively expensive. Thus the Laboratory is continuing efforts to improve the reliability and payload capacity of unreinforced polyethylene balloons.

A notable advance in superpressure ballooning was made when Laboratory personnel launched a 120-foot sphere carrying 300 pounds from Chico, California, on 11 June 1964. The balloon stayed at a nearly constant altitude of 100,000 feet for three days before the flight was ended. (The main advantage of a superpressure balloon is that it can maintain a constant density altitude without releasing ballast.) The June flight proved that superpressure balloons can carry useful payloads to high altitudes and remain there for extended periods of time. In November 1964, three more superpressure balloon flights carrying 300 pounds to 100,000 feet were successfully launched from Chico.

The tandem launch and recovery system, developed by AFCRL for recovering and reusing large balloons, is shown during flight. (The black line is part of the phototheodolite system used to photograph the balloon.) In the diagram below, the configuration of the system at floating altitude is shown.



BALLOON RECOVERY TECHNIQUES: In addition to reductions in balloon cost through the development of more reliable materials, major savings were also made possible by the development of two ingenious techniques for recovering balloons after flight. Tests of both techniques were successfully carried out in the spring of 1965.

The first technique, called the "tandem launch and recovery," involves the use of two balloons. During launch, all the lifting gas is fed into a small balloon which is attached to the top of the larger main balloon. As the system ascends, the gas in the small balloon expands to inflate the main balloon, so that both are fully inflated at floating altitude. At the completion of a flight, some of the gas is valved off causing the system to descend. During descent, the gas in the main balloon flows back into the top balloon. At an altitude of about 10,000 feet, when the main balloon is completely empty, a heavy nylon sleeve, rolled up at the top of the main balloon, drops down and completely encases the balloon for recovery. The first balloon to be recovered by this technique was launched from Holloman AFB on 28 April 1965.

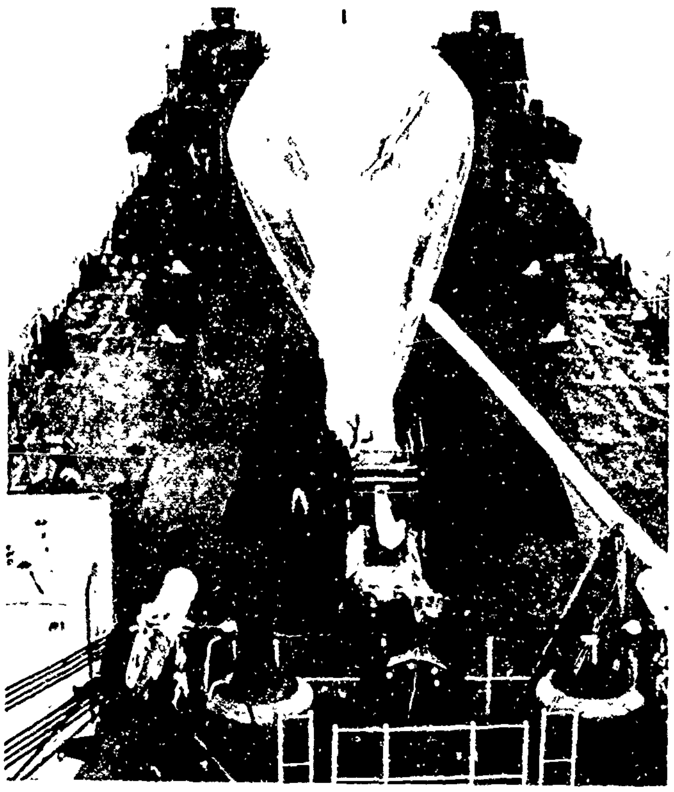
The second recovery technique also employs a sleeve that encases the balloon for recovery, but in this case a tandem balloon is not used. The reefing sleeve is carried in a canister at the base of the balloon and is attached to a parachute with a hole in the center through which the neck of the balloon is passed. When a mission has been completed, balloon descent is begun and the recovery sequence follows. Quick deflate ports at the top of the balloon are opened, venting the lifting gas and increasing the system's descent rate. This causes the parachute to open. The drag force of the parachute then pulls the sleeve up the balloon, until the balloon is completely encased for recovery. This technique was successfully tested on a flight launched from Holloman AFB on 21 May 1965. (The balloon used for this flight, a scrim balloon with a volume of 1.6 million cubic feet, was the first balloon to be made using the Flying Thread Loom discussed in the previous section.)

Balloon recovery capability is one of the most significant balloon advances in the past decade. (In the past, to terminate a flight, it has been necessary to destroy the balloon.) With the new recovery techniques, the cost per flight will be the original cost of the balloon (as much as $30,000 for a large scrim balloon) divided by the number of times it can be recovered and reused. Depending on the balloon and payload size, the reuse of scrim balloons from three to five times will make them competitive in cost per flight with the less expensive polyethylene balloons.

The tandem launch and recovery system will be used mostly with balloons carrying heavy payloads. The parachute technique is most effective for recovering balloons with payloads of less than 1500 pounds. So well did both techniques work on their initial flights, that further flights with the recovered balloons are now scheduled.

LAUNCH TECHNIQUES: Wind is the basic problem in the launching of large research balloons on land. During inflation, and particularly at the moment of launch, a balloon should stand vertical. In wind, this vertical orientation can be maintained only by carrying the payload on a special launch vehicle that travels with the same speed and direction as the wind. Although aircraft runways allow enough running space for this operation when winds are not too great, wind conditions nevertheless place considerable restriction on launchings.

Shipboard launches can overcome this difficulty. A ship can move with the wind, maintaining zero wind velocity on shipboard. In the past, however, the only ship from which a balloon could be launched was an aircraft carrier because of the large deck space needed to lay out the balloon for inflation. However, the cost of launching a balloon from a carrier is prohibitively high. This led AFCRL to develop a unique launch technique suitable for operational use on small ships. The



A balloon is being launched from the deck of the USS Wood County, by means of the shipboard launching device (shown in lower photograph) developed by AFCRL.

new technique was successfully demonstrated by AFCRL in August 1964 from the deck of a Navy LST off the coast of Virginia. The need for expansive deck space is eliminated by inflating and deploying the balloon directly from its shipping crate. A vital part of the technique is a special launcher device, which was designed and fabricated at AFCRL. This electro-hydraulic device consists mainly of a system of rollers through which the balloon is controlled during inflation and deployment.

With the shipboard launch equipment, four polyethylene balloons having a fully deployed diameter of 107 feet and carrying an 1800-pound payload, were launched in true surface wind speeds as high as 17 knots — usually prohibitively high for land launches. The ship deck space required for these operations measured only 30 by 60 feet.

BALLOON INSTRUMENTATION: During the July 1963 - June 1965 report period, the Laboratory continued to develop and improve balloon payload components for flight control, telemetry, and flight safety. This instrumentation has made possible more accurate determinations of balloon position, movement, and internal environmental conditions, and better ways of evaluating balloon design.

To control ascent and descent rates more precisely and to aid in balloon performance evaluation, the Laboratory is developing a vertical speed transducer. This instrument will be able to measure both ascent and descent rates up to 30 feet per second over an atmospheric pressure range of 10-1000 millibars with a 1-2 second response time and an accuracy of one foot per second at 10 millibars. This vertical speed transducer will be a vast improvement over the present methods which depend on successive altitude and time measurements to determine ascent and descent rates.

Once a balloon is launched it follows the wind at all levels. Prior to launch the course of the balloon is always predicted by an analysis of the wind fields and factors which affect the ascent rate. To comply with regulations for free balloon flight and to properly evaluate data from the scientific payload, the balloon's position must be known at all times. Under development is a new system for determining balloon position at large distances from a control center. This system will reduce the cost of tracking and improve accuracy of position determination. It will use bearing information from the network of omni-range navigation system ground stations that extend across the continental U. S. A VHF receiver on board the balloon will measure the bearings and retransmit them on HF to the balloon control center either at programmed intervals or on command. In several test flights, this system has provided balloon position information, accurate within five miles, even when the balloon was hundreds of miles from the ground control center.

To optimize the efficiency of command reception and data transmission by balloon-borne telemetry equipment, the Laboratory is evaluating HF antenna designs under controlled flight conditions. In the tests, a tethered balloon carries the antenna and impedance measuring equipment to an altitude of 1000 feet where it is at least ten wavelengths away from interference by objects on the ground. Under these conditions, valid, in-flight impedance measurements are obtained, so the best match between the antenna and airborne receivers and transmitters can be made.

Two new environmental sensors were developed by the Laboratory. The first is a high-precision balloon altimeter called a hypsometer. This device, which measures atmospheric pressure by measuring changes in the boiling temperature of butyl-benzene, was developed during the previous report period but became a routine inventory item during the period now under consideration. It is more than ten times as accurate as previous balloon altimeter devices. The second sensor, still under development, will provide accurate temperature measurements at the highest altitudes a balloon can go. The heart of this sensor is an improved thermistor with a larger heat-transfer coefficient that reduces errors caused by infrared radiation and other "noise." In developing this sensor, it was first found that attaching four leads to a thermistor instead of the usual two, improved the thermistor's performance. A further improvement was made when the usual platinum-iridium leads were replaced with tungsten leads having a high thermal conductivity. The new temperature sensor has a shorter response time and can take a higher measuring current. It should be accurate to 0.2 degrees C at 150,000 feet.

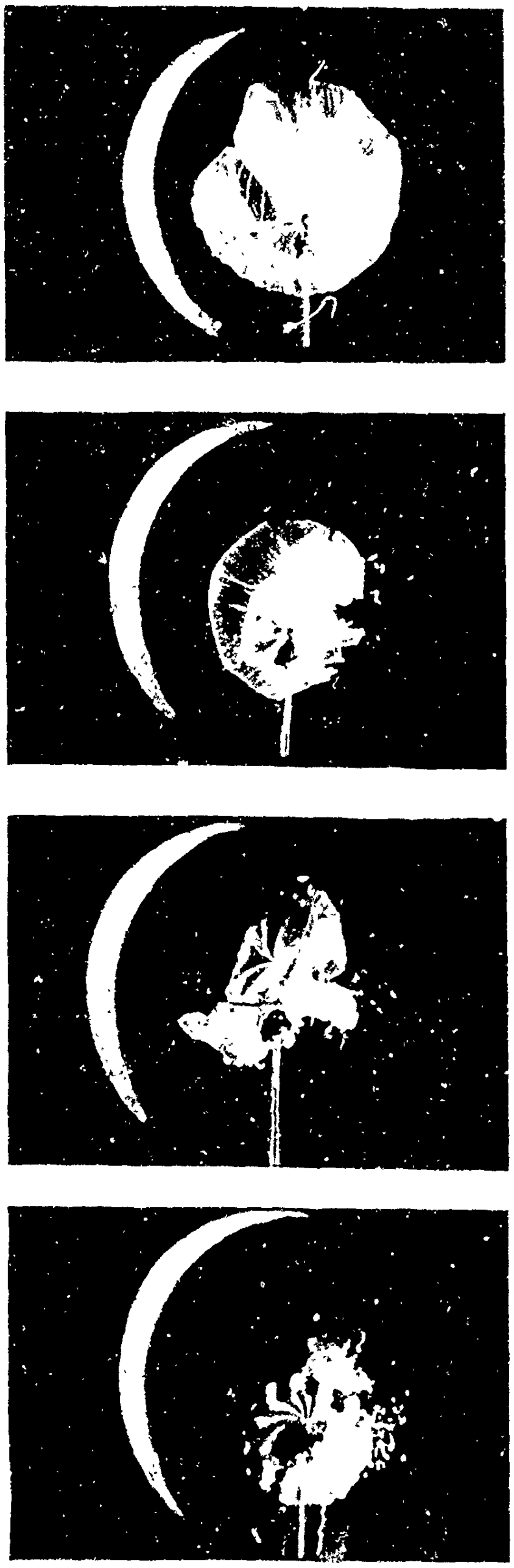
To help evaluate balloon designs, a special camera was developed and flown with excellent results. Basically a movie camera, it photographs balloon deployment, and balloon shape changes during ascent to altitude. The camera frame rate can be varied between one, two, and four per second. This rate can be controlled by a programmed timer, by pressure altitude change, or by radio command from the ground.

BALLOON BEHAVIOR AND ENVIRONMENT: Station-keeping, or hovering, is desirable when balloons are used for communications or reconnaissance. Free-floating balloons obviously will maintain a relatively stationary position with respect to the ground if there is little or no wind. With this in view, Laboratory scientists conducted a preliminary search for high-altitude minimum wind fields. They found that such minimum wind fields do exist during the summer months. Their study also provided information on the temporal and spatial characteristics of these fields between 30 and 60 degrees north latitude.

Another Laboratory study concerned the environmental factors influencing a balloon's rate of ascent. These factors are infrared and solar radiation and ambient temperatures. Of these three, only ambient temperatures are routinely observed. To develop a more accurate method of predicting balloon ascent rates, Laboratory scientists are studying the relationship between ascent rate and temperature lapse rate. (The temperature lapse rate is the vertical temperature gradient.)

A set of regression curves has been developed relating ascent rate to free lift and temperature lapse rate. These are currently being tested with independent data for operational use. The goal is to be able to make better predictions of balloon climbout trajectories, which are dependent on ascent rate and winds.

A study of the constancy of the winds in the lower stratosphere has been completed. The study provides data and information that will assist in planning and scheduling balloon flights. The study additionally provides general



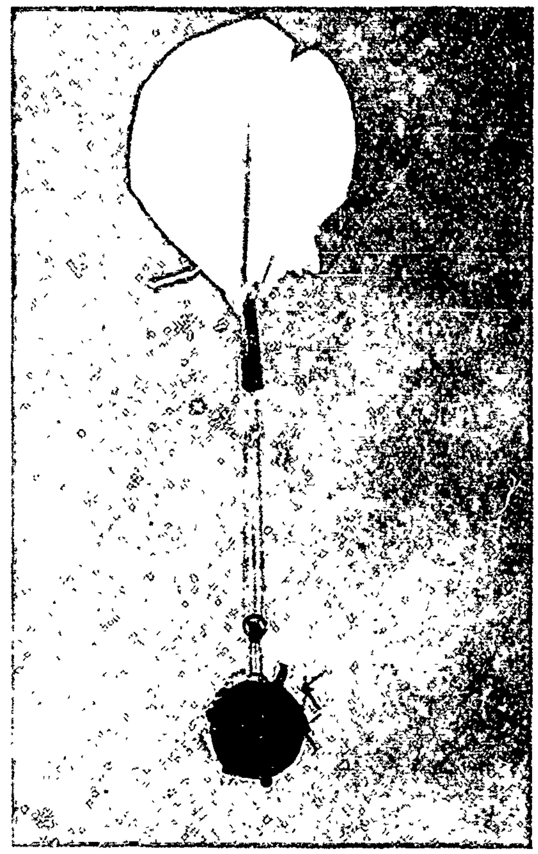
This series of photographs, showing a balloon that was designed to burst during flight, was studied by Laboratory personnel for clues to methods for improving balloon design.

knowledge on the time-space variability of upper-level winds.

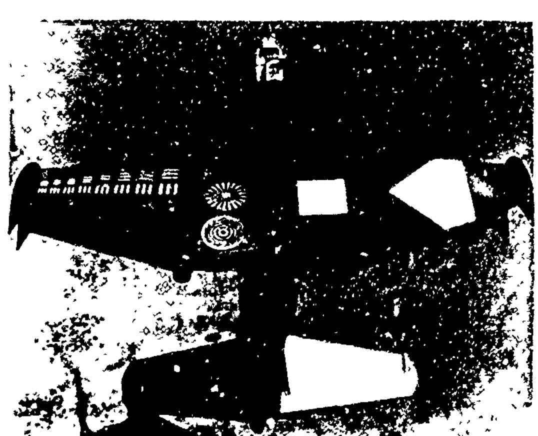
With respect to the design of scientific payloads, a computer program was written to simulate the effect of a near-space environment on the internal temperature of an insulated package suspended beneath high altitude balloons. The program's accuracy was proved on several flights made in the spring of 1964. Temperatures measured in the flight packages were close to the computed values, and it was concluded that the program accurately simulates the effect of various insulations, surface coatings, package sizes and heating elements. Thus, with the help of this program, a balloon user can design an insulated payload that will keep the internal temperature within the safe operating limits of his instrumentation during flight.

BALLOON SUPPORT PROGRAM: During the report period, the Laboratory supported a number of agencies, both governmental and non-governmental, in 22 different programs requiring balloon flights. Some of the more significant of these programs are summarized below.

Two series of balloon flights were conducted for NASA, both involving drops of space vehicles of various configurations to test recovery systems. One series, in support of Project Surveyor, also served to test the vehicle's retro rocket engines that will be used for a soft landing on the moon. The test vehicles are dropped from a tethered balloon at an altitude of 1200 feet. This series was begun during the previous report period, and twenty-six flights were made during the present period. The other series, in support of the biosatellite program, consists of balloon drop tests of the reentry vehicle from altitudes between 88,000 and



The package being carried aloft by the balloon (above) contains equipment to photograph various targets, including those painted on the RB-57 (below) from altitudes above 80,000 feet. AFCRL is supporting the Air Force Systems Command in this series of experiments designed to gather data on the effects of atmosphere turbulence on high altitude photo reconnaissance.



100,000 feet to demonstrate the performance of the recovery subsystem of this special satellite which is designed to carry biological specimens into space. The first successful test drop was made in March 1965. There have been five subsequent tests.

Another series of balloon flights was made for the Air Force Systems Command in a program concerned with photographic reconnaissance techniques. Photographic equipments weighing about 3000 pounds were carried to altitudes between 70,000 and 100,000 feet where they remained for four hours while taking pictures of specially marked ground targets and aircraft. The purpose of these flights is to determine, quantitatively, the effects of atmospheric turbulence on photographic resolution. Eleven flights were made during the report period.

Several balloon astronomy flights were carried out. In these flights, large telescopes were carried to altitudes above all but a fraction of one percent of the atmosphere. Two of these flights, conducted for the Johns Hopkins University in 1964, were successful in obtaining infrared spectra of the planet Venus which gave strong evidence of water vapor in the Venus atmosphere, and ice crystals in the Venus cloud layer. (The research was sponsored by AFCRL's Space Physics Laboratory.) The most recent balloon astronomy flight, called SKY TOP — an AFCRL program — took place on 12 August 1965, and was designed to obtain infrared spectra of the moon.

METEOROLOGICAL EQUIPMENT

The Laboratory develops meteorological equipment for the Air Weather Service. This equipment includes sounding balloons, small rockets and various sensors for routinely obtaining wind, temperature, density and humidity profiles of the atmosphere. Soundings to 200,000 feet are now routine and 600,000-foot systems are in development. The Laboratory also develops sensors for determining surface layer atmospheric conditions prior to missile launches and for general airfield use. Some items, development of which was begun during the previous report period, reached completion and entered the Air Force inventory. Groundwork was laid for many equipments involving advances in the state of the art. This progress is reported in the following sections.

SOUNDING ROCKETS: During the reporting period, the Laboratory successfully demonstrated a new, miniaturized rocket sounding system that offers marked advantages in cost, size, ease of handling and high surface wind tolerance over meteorological rockets used in the past.

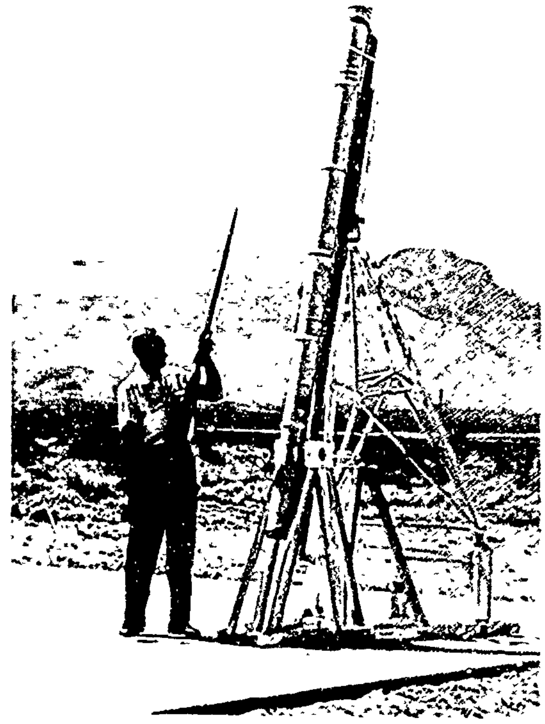
Called the Judi-Dart, the complete system weighs only 32 pounds and is 9½ feet long. During launch, the Judi booster, an improved version of the Loki, which was originally an anti-aircraft rocket, fires for two seconds and attains a velocity of 5000 feet per second. At burnout, which occurs at roughly one mile, the unpowered Dart upper stage separates and coasts with the payload to 200,000 feet. At this altitude, the payload is ejected and descends by parachute. As it descends, it telemeters temperature data to a ground station. Radar tracking of the metalized parachute provides altitude and wind information.

Although the Loki- (or Judi-) Dart system has been used previously in rocket meteorology, its use was confined to the release of chaff in the upper atmosphere for radar tracking. By developing miniaturized instrumentation which can fit into the 1⅜ inch diameter Dart and withstand the rocket's 200 g acceleration, the Laboratory has made it possible for the Air Weather Service to obtain the same data at less than half the cost of the much larger ARCAS rockets used currently.

During the report period, AFCRL provided ten high-altitude meteorological rocket systems for launching at Cape Kennedy in support of Project Gemini flights. The rocket system used in this program is the Sidewinder-ARCAS combination which carries a 12-pound payload to 400,000 feet. Prior to a Gemini flight, a Sidewinder-ARCAS is launched to obtain precise wind, density, and temperature measurements in the area of the Gemini vehicle launch trajectory. When the second stage ARCAS reaches apogee, a three-or-five-foot spherical balloon is ejected. This balloon, designated ROBIN, is made of thin plastic with a metal coating that enables radar to track it as it falls. From the path of the falling balloon, wind velocity, atmospheric density, and other parameters can be derived. The Sidewinder-ARCAS combination was developed for AFCRL by the U. S. Naval Missile Center.

For more routine wind and density measurements the standard 1-meter ROBIN falling sphere is carried aloft by a single-stage ARCAS rocket. The ARCAS-ROBIN combination is used for measurements in the 100,000 to 200,000 feet altitude regime. During the report period, large quantities of this system were procured for Air Force operational use.

To develop a falling balloon system for measuring density up to 600,000 feet, the Laboratory conducted a preliminary feasibility study of a concept involving the ejection of a spinning array of plastic arms. As the array falls, the spin rate will decrease as a function of increasing density.



A new meteorological rocket, the Judi-Dart, is being readied for launch. This new rocket, developed under AFCRL contract, offers marked advantages in cost and size over meteorological rockets used in the past.

SOUNDING BALLOONS: Falling spheres are used to measure wind and density at extremely high altitudes. Rising spheres are used to measure fine-scale wind profiles up to 60,000 feet. One rising balloon system, known as ROSE, is being used extensively by the Air Weather Service for routine measurements. During the past two years the Laboratory made considerable improvements in the ROSE system, resulting in a reduction of the problem of self-induced oscillations which occurred with the original configuration. The redesigned ROSE is 40 inches in diameter and is made of aluminized, ¼ mil mylar. It can reach a height of 50,000 to 60,000 feet at an average rise rate of 1000 feet per minute.

The Laboratory also made several improvements in radiosonde balloons during the report period. Under a program jointly funded by AFCRL and the Army, a more durable neoprene balloon film has been developed. In addition, development of a special cold temperature balloon film for use in the Arctic was continued. Successful flight tests were conducted with several new balloons prior to standardizing them for the Air Force inventory. One system, which actually consists of two balloons, one inside the other, can attain a height of 100,000 feet at a rise rate between 1600 and 1700 feet per minute.

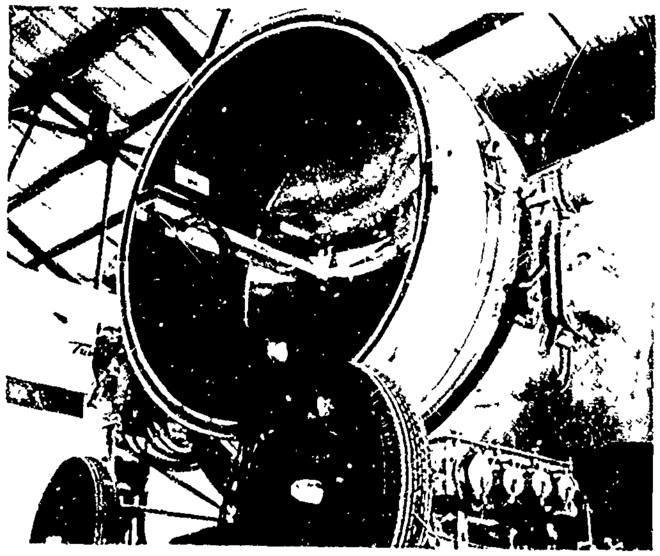
SOUNDING INSTRUMENTATION: Sounding rockets and balloons must be instrumented with miniaturized, fast response environmental sensors that are both rugged and accurate — and, because they are expendable, low in cost. Progress has been made toward the development of new temperature, humidity, and refractive index sensors to meet these requirements.

A Bremsstrahlung system for measuring atmospheric density by means of backscattered X-radiation was successfully tested in a special chamber at AFCRL (previously discussed in Chapter II). Flight testing plans are underway. The useful altitude regime of this device is 100-200 km. The large prototype version (6 inches in diameter and 50 inches long) requires an Apache rocket. Before the device can be scaled down to meteorological rocket size, its capabilities must be tested in a realistic aerospace environment. Since it measures X-ray backscatter, it must be able to distinguish between the scattered radiation and atmospheric X-rays.

Progress was also made in an effort to develop an inexpensive, easily produced aluminum oxide radiosonde humidity element with improved cold temperature characteristics. Responses at temperatures as low as –90 degrees C have been obtained. (The presently used ML-476 carbon element is virtually useless below –20 degrees C.)

Other sensors developed and tested during the period included a device for measuring the dewpoint by means of alpha radiation, originally developed for aircraft use, and a radiosonde element to detect the bases and tops of clouds. In addition, successful flight tests concluded the first phase in the development of a multichannel transponder radiosonde to handle the higher data rates associated with new sensors such as those described above. Work on a high-data-rate radiosonde for low-level soundings was also begun. Development continued on a microwave refractometer for measuring the atmosphere's refractive index.

CLEAR AIR TURBULENCE: Clear air turbulence (CAT) is the probable cause of a number of military and civilian aircraft accidents. The Aerospace Instrumentation Laboratory has intensified its efforts to find CAT detection techniques. These efforts are closely coordinated with those of a number of other agencies — the FAA, the U. S. Weather Bureau, the Navy, and NASA. The primary goal is to develop a device for sensing CAT remotely, exploiting characteristic changes in one or more atmospheric parameters such as temperature, ozone concentration, electric field or wind shear. Various active and passive sensors are being considered to allow the turbulence to be detected by an aircraft well in advance of actual penetration. In a separate approach, consideration has been given to improving routine, in-flight quantitative measurements of turbulence intensity. Stanford Research Institute, under an AFCRL contract, instrumented a number of commercial DC-8 passenger and cargo aircraft with electric field measuring equipment to determine the relationship between clear air turbulence and electric field. This program is continuing, and results to date have been encouraging. Honeywell, also under contract, has finished laboratory testing of a pulsed optical radar (laser) for detecting CAT in advance of an aircraft. During the latter part of the report period, a field test site was established in Colorado to test a high-powered, high-repetition rate pulsed laser radar for its ability to detect turbulence associated with mountain waves. This step is a prelude to flight tests in an aircraft. Other attacks on the clear air turbulence problem included investigations by the Laboratory of infrared and microwave radiometric techniques and of the temperature gradient technique. This last technique, which relies on detecting a temperature change of a few degrees C several minutes before the turbulence would be encountered, seemed promising at first, but an analysis of earlier Project Jet Stream flight data has cast serious doubt on the effectiveness of the technique.

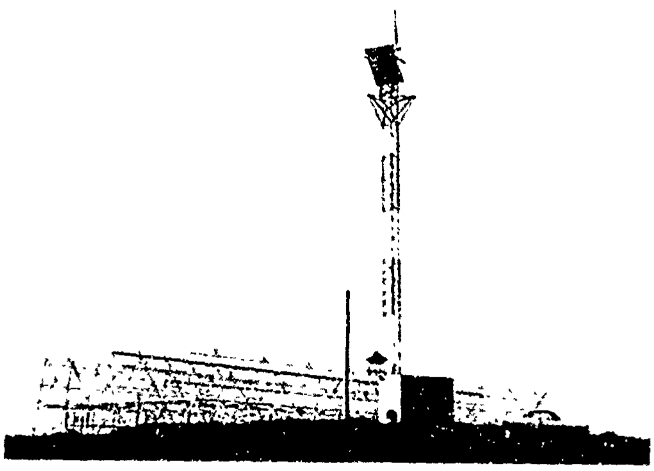


A laser radar device, developed for AFCRL by Honeywell, is being tested as a possible means of detecting clear air turbulence (CAT) in advance of an aircraft.

GROUND-BASED EQUIPMENT: In no aspect of Air Force operations is precise current knowledge of meteorological events more critical than at rocket and missile launch sites. The Laboratory worked on two systems — one still experimental, the other now under operational evaluation — for installation in the Cape Kennedy area. One is a system whereby upper atmosphere wind velocities can be continuously monitored from the ground. The other is a system for monitoring the approach of electrical storms.

The experimental system for monitoring wind velocities in the upper atmosphere is being evaluated at a site in Havana, Illinois, and was developed for AFCRL by the Smithsonian Astrophysical Observatory. The system uses ionized meteor trails as a natural tracer of upper atmosphere winds. (Another system, under development by the Meteorology Laboratory, Chapter VIII, uses meteor trails to obtain the same kind of information, but has a completely different system configuration.)

The radar system consists of one main transmitting and receiving station and eight subsidiary receiving stations, spaced over an area of several square miles. The principle on which the radar system operates is as follows: As meteoroids burn up on entering the



Radar reflections from meteor trails are received by this antenna which is part of an experimental network of eight such stations in Havana, Illinois, built jointly by AFCRL and NASA for the purpose of measuring wind velocities in the upper atmosphere. Tower is used for microwave communications between stations.

earth's atmosphere, they leave ionized trails, which are dense enough at altitudes between 80 and 95 km to reflect radar signals. Since these trails move with the wind, tracking them provides information on wind speed and direction. The most difficult part of the operation is locating the trails. This is why several stations are required. The Illinois system is being investigated also as a density measuring system. If it proves successful, a similar network may be established near Cape Kennedy to provide upper atmosphere wind and density information for missile and space shots.

Lightning storms are potentially one of the most dangerous meteorological events associated with missile launches. For several years, AFCRL has worked on systems to provide advanced warning of conditions likely to lead to such storms. The systems have been installed in the Cape Kennedy area and have employed several separate sensors. One system features an automatic lightning flash detector and a means for detecting changes in the electrical potential in the atmosphere. This is done by corona current detectors. A more sophisticated three-station network measures sferics activity at 500 kc, furnishing azimuth data, and rate and spectrum analyses. It is used with radar to pinpoint dangerous storm cells.

An improvement in the vertically-pointing AN/TPQ-11 was undertaken with the development of a radar data integrator to bring about a ten db increase in sensitivity. Essentially, the integrator consists of a magnetostrictive delay line which combines a number of returning radar echoes before readout so that output represents the average value of many single pulses. In this way, a sharper, more meaningful image is displayed, cloud heights and boundaries can be determined with greater accuracy, and faint cloud systems can be more readily detected. Although techniques for integrating radar data have been around since the 1940's, they have either entailed complex data processors and were thus expensive, or they employed simple resistance-capacitance schemes which compromised information content. The AFCRL integrator is relatively inexpensive, but does not sacrifice accuracy and resolution. It is being built under contract and is scheduled for tests in early 1966.

Development was completed on several items of portable meteorological equipment designed for use in Air Force tactical operations. These items included sets for measuring wind, night visibility, cloud height, and temperature dewpoint. They were incorporated in a mobile meteorological van capable of being airlifted. Another portable meteorological system was developed for paratroop drops. Rugged and compact, it will be used by Air Weather Service lead jump teams to obtain temperature, wind, humidity and pressure measurements in paratroop drop areas.

DESIGN CLIMATOLOGY

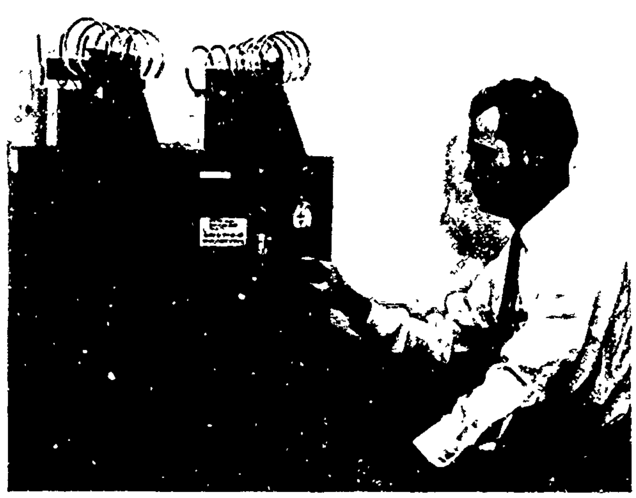
Climatology is the study of the average characteristics of the atmosphere and its variability over a particular geographical region. "Design" climatology is used to denote AFCRL's somewhat restricted interest. AFCRL is primarily interested in those climatological factors that must be taken into account by the designers of Air Force missiles and aircraft. Knowledge of atmospheric parameters may require a high design tolerance in some cases. In others, such knowledge may preclude unnecessarily high engineering tolerances.

The product of this activity is frequently standard reference graphs and tables on vertical profiles of wind, temperature and density and their time variation. For some data special observations must be made, as in the case of stratospheric humidity measurements discussed later.

ATMOSPHERIC STANDARDS: In December 1962, the "U. S. Standard Atmosphere, 1962," to which the Laboratory made important contributions, was published. This publication supplanted the earlier 1958 Standard Atmosphere. The 1962 Standard Atmosphere is a collection of tables of average temperature and density conditions at altitude intervals up to 700 km. Through scores of rocket and balloon measurements (of the type discussed throughout this report), AFCRL provided a large share of the basic data contained in the Standard Atmosphere.

To update this Standard Atmosphere, the U. S. Committee on Extension of the Standard Atmosphere accepted for publication in 1965, a set of supplemental tables, prepared by the Laboratory, listing seasonal variations in atmospheric conditions by 15-degree intervals of latitude. These tables have been issued, in abbreviated form, as "Air Force Supplemental Atmospheres." The Upper Atmosphere Physics Laboratory made major contributions to this supplement.

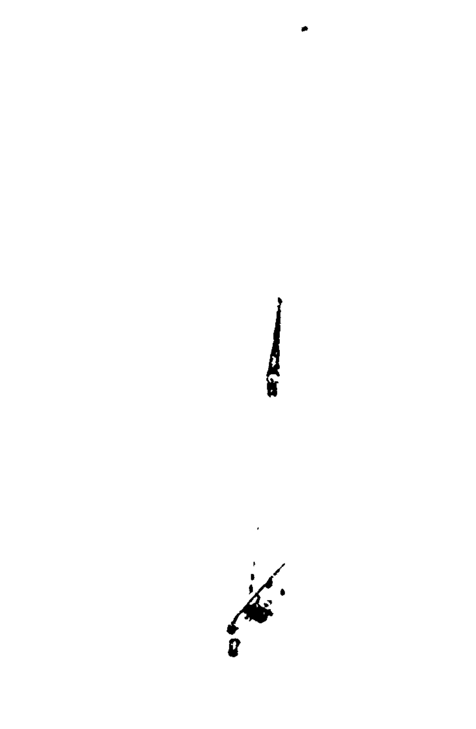
The preparation of these materials led to extensive studies of the possibility of various horizontal and vertical gradients of density. These studies were motivated by many requests for data from the aerospace vehicle designers. A survey of information on these



This device is used to monitor bursts of radio static produced by electrical discharges (sferics) in clouds. It is one of several experimental equipments which AFCRL investigated as possible lightning warning devices for U. S. missile ranges.

gradients was prepared. A sequel to this effort, now awaiting publication, is a set of monthly atmospheres for latitudes 30, 45 and 60 degrees. These provide the maximum detail of atmospheric profiles to 80 km that can be determined with the data available to date.

Tropospheric wind profiles are still the most critical geophysical constraint on the design of aerospace launch vehicles, and are often the determining factor in strength versus payload trade-offs. Most recent studies by the Air Force Flight Dynamics Laboratory, an AFCRL partner in this program, indicate that these profiles should be detailed for at least every thousand feet of altitude. Such detail, when applied in computer design exercises, requires computer resources. Current efforts are to develop a mathematical-statistical technique to substitute for the "brute force" method of utilizing a representative sample of soundings.



The AFCRL balloon payload used to measure water vapor in the stratosphere is shown just after launch. The cylinder, which contains an ultrasensitive hygrometer, is attached to a reel so that it can be lowered far enough below the balloon to prevent contamination by water vapor carried aloft by the balloon itself.

Other climatology studies, relating to the design of proposed hypersonic vehicles and supersonic aircraft, are also being conducted. One such study is an attempt to obtain measurements of small-scale wind motions, both random turbulence and systematic waves, which might affect the flight of hypersonic vehicles designed to cruise at altitudes between 100,000 and 200,000 feet. In another study, consideration of the operation of supersonic jet transports at altitudes somewhat below 100,000 feet has aroused concern about temperature anomalies which could greatly alter the range and speed of such aircraft. Although very complete data on temperature distribution at the climb and cruise altitudes of a supersonic transport are available, there have been no studies on the probability of large anomalies persisting for various distances along air routes. The Laboratory is currently undertaking the development of mathematical-statistical models to describe the horizontal extent of these anomalies.

STRATOSPHERIC HUMIDITY: A new series of observations was undertaken to determine stratospheric humidity up to 100,000 feet. Knowledge of the humidity in the earth's upper atmosphere is needed to evaluate the design and performance of satellite infrared detectors. To make humidity measurements, balloons are instrumented with extremely sensitive alpha radiation dewpoint hygrometers. During flight, these sensors are reeled down 2,000 feet below the balloon to prevent contamination by moisture carried aloft on the surface of the balloon. However, despite this precaution, contamination by balloon moisture is still considered a possible source of error. As a further precaution against this error, measurements are made during the balloon's descent rather than ascent. (During ascent, the instrumentation passes through the balloon's wake, thus measuring whatever moisture is picked up from the balloon by the surrounding air.)

Two types of flights are being made. The first consists of simple, direct ascent and descent, in which the balloons remain aloft seven to eight hours. The second consists of long duration, horizontal flights, during which the balloons remain aloft for ten to twelve days at altitudes between 70,000 to 80,000 fect. Under this program, short duration, vertical flights to 87,000 feet began in January 1965. Schedules call for two flights per month through December 1965. As of 30 June 1965, about half these flights have been successful, and have yielded some very significant results. Five long duration flights are scheduled, but none had been flown at the termination of the report period.

The vertical flights have uncovered layers of relatively high moisture concentrations in the stratosphere. This was a completely unexpected result because it had been thought that the amount of water vapor in the atmosphere decreased linearly with altitude. Moist layers in the stratosphere had not been previously observed. This preliminary result has aroused much interest, and investigations of the water vapor anomalies are being continued.

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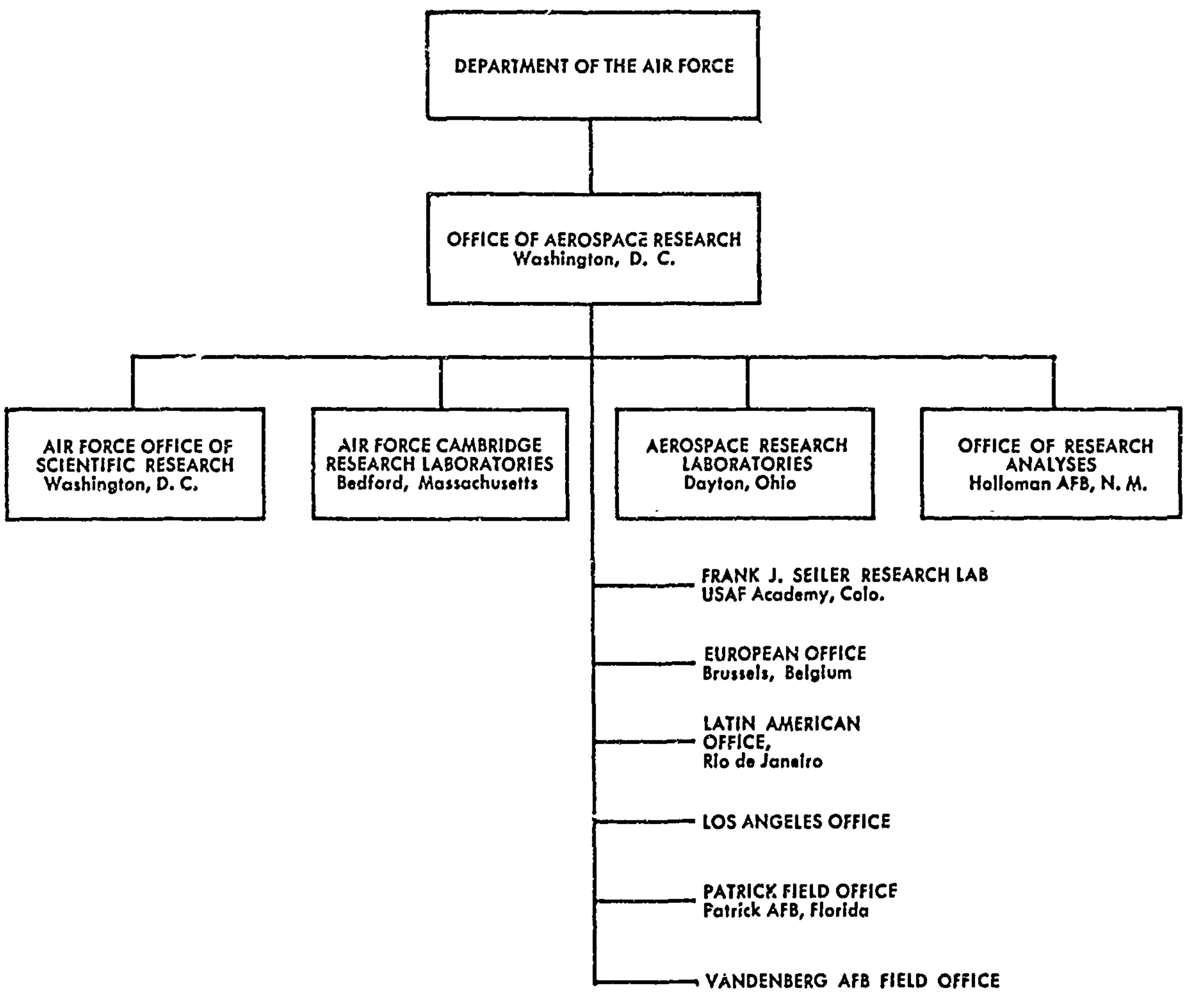
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Deputy	Lt Col B. E. Allran
Assistant Deputy	J. J. Brady

CRSA ADMINISTRATIVE MANAGEMENT DIVISION

Chief		J. M. Linda
CRSAM	Mail Distribution	R. R. Wagner
CRSAR	Records Management	J. E. Cavanagh
CRSAS	Security	G. J. Cody
CRSAT	Travel	B. Barron

CRSP PERSONNEL MANAGEMENT DIVISION

Chief		J. P. Cushman
CRSPC	Management Services	F. Marelli
CRSPM	Military Personnel	M/Sgt S. Greenacre
CRSPP	Procedures	J. V. Ierardi

CRM DEPUTY FOR LOGISTICS

Deputy	V. S. Dempsey
Assistant For Logistics	S. E. Toye
Assistant For Technical Services	J. T. Cooney

CRMM MATERIEL DIVISION

Chief		W. F. Brooks
CRMMM	Materiel Management	F. G. Murphy
CRMMP	Materiel Procedures	G. Sinkevich
CRMMR	Materiel Requirements	E. J. Gullage

CRMP LOGISTICS PLANS DIVISION

Chief		J. D. Murphy
CRMPC	Special Contractural Services	R. Perocchi
CRMPF	Technical Facilities	J. L. Burns
CRMPR	Field Requirements	J. F. Murphy

CRMX TECHNICAL SERVICES DIVISION

Chief		J. T. Cooney
CRMXA	Data Analysis	E. C. Cronin
CRMXD	Computer Processing	R. G. Gosselin
CRMXE	Engineering and Instrumentation	R. Ebacher
CRMXL	Research Library	O. Groos
CRMXP	Technical Photography	C. Rodberg
CRMXR	Publications	J. Marple
CRMXS	Experimental Support	A. Cate*

CRI RESEARCH INFORMATION OFFICE

Chief	L. E. Woods

CRIE INFORMATION DIVISION

Chief	H. Novak

CRIH HISTORICAL RECORDS DIVISION

Chief	L. E. Woods*

*ACTING

AFCRL Laboratories

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BRIG GEN L. A. KILEY
VICE COMMANDER
COL J. L. DICK

CRB DATA SCIENCES LABORATORY

Chief		R. M. Alexander
Senior Scientist — Computer Sciences		H. Zschirnt
CRBA	Applied Mathematics	R. H. Urbano
CRBD	Logic Technology	M. E. Brooking
CRBG	Synthetic Coding	J. C. Mott-Smith
CRBI	Dynamic Processes	C. M. Walter
CRBK	Information Theory	C. F. Hobbs
CRBR	Biophysics	T. A. Kalin
CRBS	Digital Speech Compression	C. P. Smith
CRBS	Speech Research	W. Wathen-Dunn

CRD MICROWAVE PHYSICS LABORATORY

Chief		C. J. Sletten
CRDA	Microwave Interactions & Analysis	W. W. Gerbes
CRDG	Radiation & Reflection	P. Blacksmith
CRDM	Plasma Electromagnetics	W. Rotman
CRDT	Transmission	E. Altshuler
CRDW	Waves & Circuits	F. J. Zucker

CRE AEROSPACE INSTRUMENTATION LABORATORY

Chief		R. M. Slavin
Senior Engineer		C. S. Tilton
Senior Scientist — Design Climatology		N. Sissenwine
Senior Engineer — Meteorological Equipment		A. S. Carten
CREA	Balloon Flight Requirements Analysis	T. J. Danaher
CREB	Balloon Research	T. W. Kelly
CREC	Balloon Instrumentation	C. S. Tilton
CREF	Experimental Balloon Activities	F. X. Doherty
CREH	Balloon Research & Development Test	Lt Col M. S. Kretow
CREI	Research Probe Instrumentation	C. H. Reynolds
CREK	Research Probe Flight	P. Gustafson
CREM	Weather Station Equipment	R. Guenthner
CREP	Indirect Probing Techniques	W. Paulsen
CRER	Vertical Sounding Techniques	R. Leviton
CRES	Direct Sensing Techniques	J. F. Morrissey
CREU	Equipment Engineering and Evaluation	A. S. Carten
CREW	Design Climatology	N. Sissenwine

CRF SPACE PHYSICS LABORATORY

Chief		Maj. T. D. N. Douthit
Senior Scientist — Astrophysics		H. K. Sen
Senior Scientist — Auroral Physics		N. J. Oliver
Senior Scientist — Electrochemistry		N. Rosenberg
Senior Scientist — Radio Astronomy		J. Aarons
CRFA	Plasma Astrophysics	M. A. Levine
CRFC	Cosmic Radiation	L. Katz
CRFE	Energetics	N. Yannoni
CRFG	Geomagnetism	J. McClay
CRFL	Lunar-Planetary Research	J. W. Salisbury
CRFM	Meteor Physics	R. K. Soberman
CRFR	Radio Astronomy	J. Aarons
CRFS	Sacramento Peak Observatory Director	J. W. Evans
CRFW	Space Forecasting	G. M. DeGiacomo

CRH METEOROLOGY LABORATORY

Chief		M. L. Barad
Senior Scientist — Heat Transfer		C. N. Touart
CRHA	Weather Radar	D. Atlas
CRHB	Boundary Layer	D. A. Haugen
CRHC	Cloud Physics	R. M. Cunningham
CRHD	Dynamics	R. Shapiro
CRHO	Satellite Meteorology	T. J. Keegan
CRHU	Upper Atmosphere	W. S. Hering

CRJ TERRESTRIAL SCIENCES LABORATORY

Chief		O. W. Williams
Senior Scientist — Wave Propagation		N. A. Haskell
CRJG	Geodesy	O. W. Williams*
CRJL	Gravity	B. Szabo*
CRJT	Geotechnics	Capt D. W. Kick
CRJW	Wave Propagation	Maj R. A. Gray

CRO OPTICAL PHYSICS LABORATORY

Chief		J. S. Garing
Senior Scientist — Infrared Physics		H. Fischer
CROA	Atmospheric Optics	R. B. Toolin
CROI	Infrared Physics	R. G. Walker
CROL	Laser Physics	P. E. Schweitzer
CROO	Radiometry	L. Block
CROR	Radiation Effects	H. P. Gauvin

CRU UPPER ATMOSPHERE PHYSICS LABORATORY

Chief		C. G. Stergis
Senior Scientist — Solar Ultraviolet		H. Hinteregger
Senior Scientist — EM Propagation		P. Newman
Senior Scientist — Ionospheric Physics		W. Pfister
Senior Scientist — Spectroscopy		Y. Tanaka
CRUA	Aurora & Airglow	S. Silverman
CRUB	Atmospheric Structure	K. S. W. Champion
CRUE	Electromagnetic Environment	E. A. Lewis
CRUI	Ionospheric Perturbations	N. W. Rosenberg
CRUP	Ionospheric Properties	K. Toman
CRUQ	Ionospheric Propagation	M. S. Wong
CRUS	Spectroscopic Studies	A. Jursa
CRUU	Solar Ultraviolet	H. Hinteregger
CRUZ	Composition	R. S. Narcisi

CRW SOLID STATE SCIENCES LABORATORY

Chief		R. M. Barrett
Senior Scientist — Mathematical Physics		E. W. Samson
Senior Scientist — Lattice Dynamics		J. N. Plendl
CRWA	Advanced Studies	R. M. Barrett*
CRWB	Purification and Growth	C. S. Sahagian
CRWD	Properties and Analysis	J. P. Cali
CRWE	Magnetics and Resonance	E. R. Czerlinsky
CRWF	Semiconductor Physics	C. E. Ryan
CRWG	Device Physics	R. F. Cornelisson
CRWH	Radiation Effects	C. D. Turner

*Acting

Appendix B

AFCRL PROJECTS BY PROGRAM ELEMENT

Program Element	Project Number and Title		Lab
61430014	*IN-HOUSE LABORATORY INDEPENDENT RESEARCH*	OAR*	
	0000 Laboratory Director's Fund		CRTP**
61445014	*DEFENSE RESEARCH SCIENCES*	OAR	
	5620 Synthesis and Properties of Electromagnetic Materials		CRW
	5621 Crystal Physics		CRW
	5628 Communications Processes		CRB
	5629 Radio Astronomy and Astrophysics		CRF
	5631 Ionospheric Radio Physics		CRU
	5632 Research in Electronic Information		CRB
	5633 Upper Atmospheric Dynamics		CRU
	5634 Research in Optical Physics		CRO
	5635 Electromagnetic Radiation		CRD
	8600 Research on Cosmic Radiation		CRF
	8601 Research in Geomagnetism		CRF
	8602 Lunar-Planetary Spectra		CRF
	8603 Research on IR and Optical Techniques		CRO
	8604 Meteorological Research		CRH
	8605 Upper Atmosphere Structure		CRU
	8607 Basic Research in Geodesy and Gravity		CRJ
	8608 Rsch on Plasma Dynamics for Application to Astrophysics		CRF
	8617 Electrical Structure of Aerospace		CRU
	8620 Research on Cloud Physics		CRH
	8623 Geologic Properties: Minerals, Landforms and Crust		CRJ
	8627 Spectroscopic Studies of UA Processes		CRU
	8635 Research on Physical Processes		CRF
	8647 Rsch on Magnetohydrodynamics and Space Physics		CRF
	8654 Aerospace Geodesy		CRJ
	8658 IR Non-Equilibrium Radiative Mechanisms		CRO
	8659 Energetics Processes Research		CRF
61535015	*ARPA*		
	8668 Bilateral Communications Between Men and Machines Through Conversation (Order #627)		CRB
	8672 Methods of Formal Reasoning by Machine (Order #700)		CRB
	8673 Participation in and Development of Programming Language for the M44 Time-Sharing System (Order #696)		CRB
62405274	*ELECTROMAGNETICS—SPACE*	AFSC-ASD	
	4427 T-442702 Inst for High Altitude Probe to Measure IR		CRO
62405304	*ELECTROMAGNETICS—OTHER*	AFSC-OAR	
	4600 Electromagnetic Radiation Techniques		CRD
	4610 Information Processes for Communications		CRB
	4641 Advanced Data Processing Technology		CRB
	4642 Interaction of EM Radiation with Ionized Flow Fields		CRD
	4648 Methods for Processing Complex Information		CRB

62405314	*ELECTRONIC DEVICES — OTHER*	AFSC-AFAL	
	4608 Solid State Device Physics		CRW
	4645 Advanced Device Physics		CRO/B
62405394	*ENVIRONMENT*	OAR	
	4603 Ionospheric Propagation		CRU
	4643 Radio and Radar Astronomy		CRF
	6020 Aircraft Meteorological Sensors and Techniques		CRE
	6670 Atmospheric Sensing Techniques		CRE
	6672 Weather Radar Techniques		CRH
	6687 Aerospace Composition		CRU
	6688 Aerospace Radiation		CRU
	6690 Aerospace Density		CRU
	6698 Satellite Meteorology		CRH
	7600 Geodesy for Naviguidance		CRJ
	7601 Electric and Magnetic Fields		CRF
	7605 Weather Modification		CRH
	7621 Atmospheric Optics		CRO
	7628 Terrestrial Geology		CRJ
	7635 Upper Atmosphere Chemical Physics		CRU
	7637 Air Pressure Pulse		CRJ
	7639 Elastic Wave Propagation Studies		CRJ
	7649 Solar Environmental Effects		CRF
	7655 Micrometeorology		CRH
	7659 Aerospace Research Instrumentation		CRE
	7661 Aurora and Airglow		CRU
	7663 Ionospheric Characteristics		CRU
	7667 Meteor Physics		CRF
	7670 Geophysical Effects on IR Radiation		CRO
	7698 Extraterrestrial Environment		CRF
	8624 Variability of Meteorological Elements		CRE
	8628 Free Air Circulations		CRH
	8631 Ozone Variability		CRH
	8666 Space Environment Observing and Forecasting Techniques		CRF
62405454	*SURVEILLANCE*	AFSC-RADC	
	4649 Over-the-Horizon Detection		CRU
	4691 Upper Atmosphere Perturbation		CRU
62503015	*ARPA*		
	4406 Ionization in Missile Trails (Order #234)		CRU
	4781 Ionospheric Radar Probe (Order #106)		CRD
	4783 Auroral Airglow Reaction Study (Order #111)		CRO
	4784 Rsch on Launch & Mid-Course Phenomena (Order #116)		CRO
	4793 Electrostatic Phenomena (Order #202 — Task 1)		CRF
	4904 IR-Optic Range Research (Order #30)		CRO
	4984 Afterglow Blackout Phenomena (Order #42)		CRU
	6327 Re-entry Vehicle Instrumentation (Order #254)		CRO
	8662 Optical Target Measurements (Order #363)		CRO
	8663 Optical Techniques (Order #450)		CRO
	8667 Missile Interactions (Order #556)		CRU
	8671 ECM Antenna Studies (Order #693)		CRD
62506015	*ARPA*		
	3809 VELA HOTEL Radiometers (Order #213, Task 1)		CRU
	3809 Photo-Electron Emission Measurements (Order #213, Task 2)		CRU
	7901 VELA Cloud-Gap (Order #500)		CRJ
	8652 Seismic Rsch Project VELA UNIFORM (Order #292)		CRJ
	8669 Magnetohydrodynamic Wave Propagation in the Ionosphere (Order #635)		CRU

64415064	*OTHER OPERATIONAL SUPPORT*	AFSC-RADC	
	4662 T-466205	ASTREC	CRU
65402124	*ENVIRONMENTAL RESEARCH SUPPORT*	OAR	
	6665 Plastic Balloon Components and Techniques		CRE
65402154	*TEST INSTRUMENTATION*	AFSC-ESD	
	5930 Range Trajectory/Orbital Measurements		CRH
	6682 Test Range Meteorological Support		CRE
76006015	*DASA*		
	5710 NWET		CRE/O T/U
76008015	*DASA*		
	5710 NWER		CRU/O

* Denotes Agency Having Management Responsibility for Program Element
** See Organization Chart, Appendix A, for Laboratory Title

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Appendix C

AFCRL ROCKET AND SATELLITE PROGRAM: JULY 1963 - JUNE 1965

Date	Launch Site	Vehicle	Experiment	Scientist	Results
3 Jul 63	APGC*	Aerobee 150	Electrical Structure of the Upper Atmosphere	R. Sagalyn	Success
10 Jul 63	WSMR**	Aerobee 150	Solar Extreme Ultraviolet	H. Hinteregger	Success
12 Jul 63	Vandenberg AFB	Agena PB	Emulsions	H. Yagoda	Success
20 Jul 63	Ft. Churchill, Canada	Black Brant	Electron Density (Solar Eclipse)	J. Ulwick	Success
25 Jul 63	APGC	Exos	Refractive Index Studies	M. Wong	Success
26 Jul 63	Ft. Churchill, Canada	Black Brant	Electron Density-D Region	J. Ulwick	Success
30 Jul 63	Vandenberg AFB	Agena PB	Emulsions	H. Yagoda	Success
30 Jul 63	Cape Kennedy	Scout, Jr.	Radio Noise-Electron Density	J. Ulwick	Success
21 Aug 63	Cape Kennedy	Titan Pod (2)	Missile Plume Infrared Measurements	L. Block	Success
3 Sep 63	WSMR	Aerobee 150	Composition-Neutral Constituents	R. Narcisi	Success
23 Sep 63	APGC	Nike-Apache	Firefly IV - Ionospheric Winds and Temperature	N. W. Rosenberg	Success
25 Sep 63	APGC	Nike-Apache	Firefly IV - Ionospheric Winds and Temperature	N. W. Rosenberg	Success
25 Sep 63	APGC	Nike-Apache	Firefly IV - Ionospheric Winds and Temperature	N. W. Rosenberg	Success
26 Sep 63	WSMR	Aerobee 150	Atmospheric Absorption of Ultraviolet Radiation	A. Jursa	Success
1 Oct 63	APGC	Nike-Apache	Firefly IV - Ionospheric Winds (NH_3 and TMA)	N. W. Rosenberg	Success
31 Oct 63	APGC	Nike-Cajun	Neutral Ion Composition	R. Narcisi	Success
			Ion-Electron Density	R. Sagalyn	Success
1 Nov 63	Cape Kennedy	Titan Pod (2)	Electron Density in a Missile Trail	J. Ulwick	Success
4 Nov 63	WSMR	Nike-Apache	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
4 Nov 63	WSMR	Nike-Cajun	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
6 Nov 63	APGC	Nike-Cajun	Neutral Composition (Mass Spectrometer)	R. Narcisi	Failure
13 Nov 63	WSMR	Aerobee 150	Day Airglow	S. Silverman	Success
5 Dec 63	WSMR	Aerobee 150	Solar Spectroscopy (High Resolution Spectrograph)	A. Jursa	Failure
8 Dec 63	Ft. Churchill, Canada	Astrobee 200	Auroral Studies (Dose Rate)	J. Ulwick	Failure
12 Dec 63	WSMR	Aerobee 150	Solar Extreme Ultraviolet (EUV Monochromator)	H. Hinteregger	Success
8 Feb 64	Ft. Churchill, Canada	Aerobee	Auroral Input-Output Experiment	J. Ulwick	Success
18 Feb 64	WSMR	Nike-Apache	7" Falling Sphere — Density	A. Faire	Success
19 Feb 64	WSMR	Nike-Cajun	7" Falling Sphere — Density	A. Faire	Success
11 Mar 64	APGC	Nike-Cajun	Neutral Ion Composition	R. Narcisi	Success
			Positive and Negative Ion Density	R. Sagalyn	Success
13 Mar 64	Cape Kennedy	Scout, Jr.	Magnetic Fields (High Altitudes)	R. Hutchinson	Partial
23 Mar 64	Cape Kennedy	Titan Pod (2)	Electron Density in a Missile Trail	J. Ulwick	Success
30 Mar 64	WSMR	Aerobee	Solar Spectroscopy (EUV Monochromator)	H. Hinteregger	Success
22 Apr 64	Vandenberg AFB	Agena PB	ORBIS I (Orbiting Ionospheric Beacon)	J. Mullen	Failure
17 May 64	Cape Kennedy	Nike-Apache	Redlamp — Electron Cloud (TMA)	N. W. Rosenberg	Success
17 May 64	Cape Kennedy	Nike-Apache	Redlamp — Electron Removal (SF_6)	N. W. Rosenberg	Success
18 May 64	Cape Kennedy	Nike-Apache	Redlamp — Electron Cloud (TMA)	N. W. Rosenberg	Partial
18 May 64	Cape Kennedy	Nike-Apache	Redlamp — Electron Removal (SF_6)	N. W. Rosenberg	Failure
20 May 64	WSMR	Nike-Apache	Noctilucent Clouds (test)	R. Soberman	Failure
26 May 64	WSMR	Aerobee	Lunar X-Ray Fluorescence	J. W. Salisbury	Failure
9 Jun 64	Vandenberg AFB	Astrobee 200	Expandable Sphere — Density	G. Faucher	Success
18 Jun 64	Vandenberg AFB	Atlas Pod	Missile Trail Ionization Studies	J. Ulwick	Success
26 Jun 64	Vandenberg AFB	Scout	Research Satellite for Environmental Studies	—	Failure

Appendix C

AFCRL ROCKET AND SATELLITE PROGRAM: JULY 1963 - JUNE 1965

Date	Launch Site	Vehicle	Experiment	Scientist	Results
17 Jul 64	Cape Kennedy	Nike-Apache	Redlamp (Missile Compression Wave)	N. W. Rosenberg	Failure
18 Jul 64	Ft. Churchill, Canada	Astrobee 200	Auroral and Day Airglow Emission	S. Silverman	Success
28 Jul 64	WSMR	Nike-Apache	Atmospheric Density (7″ Falling Sphere)	A. Faire	Success
29 Jul 64	WSMR	Nike-Apache	Atmospheric Density (7″ Falling Sphere)	A. Faire	Success
7 Aug 64	Sweden	Nike-Apache	Noctilucent Cloud Sampling	R. Soberman	Failure
10 Aug 64	Sweden	Nike-Apache	Noctilucent Cloud Sampling	R. Soberman	Success
16 Aug 64	Sweden	Nike-Apache	Noctilucent Cloud Sampling	R. Soberman	Success
17 Aug 64	Sweden	Nike-Apache	Noctilucent Cloud Sampling	R. Soberman	Success
26 Aug 64	APGC	Nike-Cajun	Electromagnetic Absorption	R. Harvey	Failure
4 Sep 64	Cape Kennedy	OGO-A	Positive and Negative Ion and Proton Fluxes and Energies	R. Sagalyn	Success
18 Sep 64	Cape Kennedy	Nike-Apache	Redlamp (Missile Electron Density)	N. W. Rosenberg	Failure
			Electron Density (Impedance Probe)	J. Ulwick	Failure
			Charged Particle Density	R. Sagalyn	Failure
17 Oct 64	APGC	Nike-Apache	IQSY Test — Ionospheric Winds and Temperatures	N. W. Rosenberg	Success
17 Oct 64	APGC	Nike-Javelin	Ionospheric Winds and Temperatures	N. W. Rosenberg	Success
27 Oct 64	Ft. Churchill, Canada	Black Brant	Auroral Absorption	J. Ulwick	Success
			X-Ray Proportional Counter Measurements	J. Manson	Success
			Ion Density (Ion Trap)	R. Sagalyn	Success
27 Oct 64	Ft. Churchill, Canada	Nike-Cajun	Thermal Electrons (Retarding Potential Analyzer)	J. Ulwick	Success
10 Nov 64	APGC	Nike-Apache	IQSY — Atmospheric Density (7″ Falling Sphere)	A. Faire	Failure
			Positive and Negative Ions (Ion Trap)	R. Sagalyn	Failure
10 Nov 64	APGC	Nike-Apache	IQSY — Atmospheric Density (7″ Falling Sphere)	A. Faire	Failure
10 Nov 64	APGC	Nike-Apache	Positive and Negative Ions (Ion Trap)	R. Sagalyn	Failure
10 Nov 64	APGC	Nike-Apache	IQSY — Chemical Release (Ionospheric Studies)	N. W. Rosenberg	Failure
10 Nov 64	APGC	Nike-Apache	IQSY — Chemical Release (Ionospheric Studies)	N. W. Rosenberg	Failure
18 Nov 64	APGC	Nike-Apache	IQSY — Chemical Release (Ionospheric Studies)	N. W. Rosenberg	Failure
18 Nov 64	APGC	Nike-Apache	Chemical Release (TMA)	N. W. Rosenberg	Success
18 Nov 64	Vandenberg AFB	Agena PB	ORBIS II (Orbiting Ionospheric Beacon)	J. Mullen	Success
19 Nov 64	APGC	Nike-Apache	IQSY — Chemical Release (Ionospheric Studies)	N. W. Rosenberg	Failure
21 Nov 64	Cape Kennedy	Injun IV	Positive and Negative Ions (Ion Trap)	R. Sagalyn	Success
22 Nov 64	APGC	Nike-Cajun	Electromagnetic Absorption	R. Harvey	Partial
27 Nov 64	APGC	Niro	Rocket Vehicle Test	C. Hoult	Success
8 Dec 64	WSMR	Aerobee	Solar Spectroscopy (EUV Monochromator)	H. Hinteregger	Failure
21 Jan 65	Vandenberg AFB	OV-1 Satellite	Optical Radiation	L. Block	Failure
			Micrometeorite Collection	R. Soberman	
			Radio Noise	J. Ulwick	
			Electron Density	J. Ulwick	
28 Jan 65	Cape Kennedy	Scout, Jr.	Magnetic Fields (High Altitudes)	R. Hutchinson	Failure
11 Feb 65	WSMR	Aerobee 150	Solar Radiation Features	A. Jursa	Failure
18 Feb 65	APGC	Nike-Apache	Ionospheric Winds and Temperatures	N. W. Rosenberg	Success
23 Feb 65	APGC	Javelin (DASA)	Atmospheric Density (7″ Falling Sphere)	A. Faire	Success

Appendix C

AFCRL ROCKET AND SATELLITE PROGRAM: JULY 1963 - JUNE 1965

Date	Launch Site	Vehicle	Experiment	Scientist	Results
23 Feb 65	APGC	Nike-Javelin (DASA)	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
26 Feb 65	APGC	Nike-Apache (DASA)	Atmospheric Density (7" Falling Sphere)	A. Faire	Success
26 Feb 65	APGC	Nike-Apache (DASA)	91B	N. W. Rosenberg	Failure
27 Feb 65	APGC	Nike-Apache	Neutral Ion-Electron Density	M. Smiddy A. Faire	Success
27 Feb 65	APGC	Nike-Apache	IQSY - Ionospheric Winds and Temperatures	N. W. Rosenberg	Success
27 Feb 65	APGC	Nike-Apache	IQSY - Ionospheric Winds and Temperatures	N. W. Rosenberg	Failure
27 Feb 65	APGC	Nike-Apache	IQSY - Ionospheric Winds	N. W. Rosenberg	Success
28 Feb 65	APGC	Nike-Apache	IQSY - Ionospheric Winds	N. W. Rosenberg	Failure
28 Feb 65	APGC	Nike-Apache	IQSY - Ionospheric Winds	N. W. Rosenberg	Success
28 Feb 65	APGC	Nike-Apache	IQSY - Ionospheric Winds and Temperatures	N. W. Rosenberg	Success
28 Feb 65	APGC	Nike-Apache	Neutral Ion-Electron Density	J. Ulwick A. Faire	Success
28 Feb 65	APGC	Nike-Apache	Neutral Ion-Electron Density	J. Ulwick M. Smiddy	Failure
28 Feb 65	APGC	Nike-Apache	Neutral Ion-Electron Density	J. Ulwick M. Smiddy	Failure
2 Mar 65	WSMR	Aerobee 150	Solar Spectroscopy (EUV Monochromator)	H. Hinteregger	Success
3 Mar 65	WSMR	Aerobee 150	Solar Spectroscopy (EUV Monochromator)	H. Hinteregger	Success
4 Mar 65	WSMR	Aerobee 150	Solar Spectroscopy (EUV Monochromator)	H. Hinteregger	Success
6 Mar 65	Ft. Churchill, Canada	Aerobee 150	Auroral Input - Output	J. Ulwick	Success
13 Mar 65	Ft. Churchill, Canada	Aerobee 150	Auroral Input - Output	J. Ulwick	Success
20 Mar 65	At Sea	Nike-Cajun	Electric Fields and Structures	R. Sagalyn	Success
20 Mar 65	At Sea	Nike-Apache	Variations in Magnetic Fields	B. Shuman	Success
22 Mar 65	At Sea	Nike-Apache	Variations in Magnetic Fields	B. Shuman	Success
22 Mar 65	At Sea	Nike-Cajun	Electric Fields and Structures	R. Sagalyn	Success
25 Mar 65	At Sea	Nike-Apache	Variations in Magnetic Fields	B. Shuman	Success
28 Mar 65	At Sea	Nike-Apache	Variations in Magnetic Fields	B. Shuman	Success
30 Mar 65	Cape Kennedy	Scout, Jr.	Distribution of energies in earth's inner radiation belt	L. Katz	Success
3 Apr 65	Vandenberg AFB	Atlas-Agena (SNAP 10A Satellite)	Atmospheric Density Electrical Structures Electron Density Micrometeorite Collection	J. McIsaac R. Sagalyn J. Ulwick R. Soberman	Success
12 Apr 65	APGC	Niro	Test Round of NIRO (Nike Iroquois)	S. Hoult	Success
20 Apr 65	Wallops Island, Va.	Nike-Cajun	Antenna Voltage Breakdown	C. Ellis	Success
12 May 65	Cape Kennedy	Scout, Jr.	Distribution of energies in earth's inner radiation belt	L. Katz	Success
25 May 65	APGC	Exos	VLF Propagation	R. Harvey	Success
25 May 65	APGC	Exos	VLF Propagation	R. Harvey	Success
2 Jun 65	APGC	Nike-Cajun	Ionospheric Winds and Temperatures	N. W. Rosenberg	Success
2 Jun 65	APGC	Nike-Cajun	Ionospheric Winds and Temperatures	N. W. Rosenberg	Success

* Air Proving Ground Command, Eglin AFB, Florida
** White Sands Missile Range, New Mexico