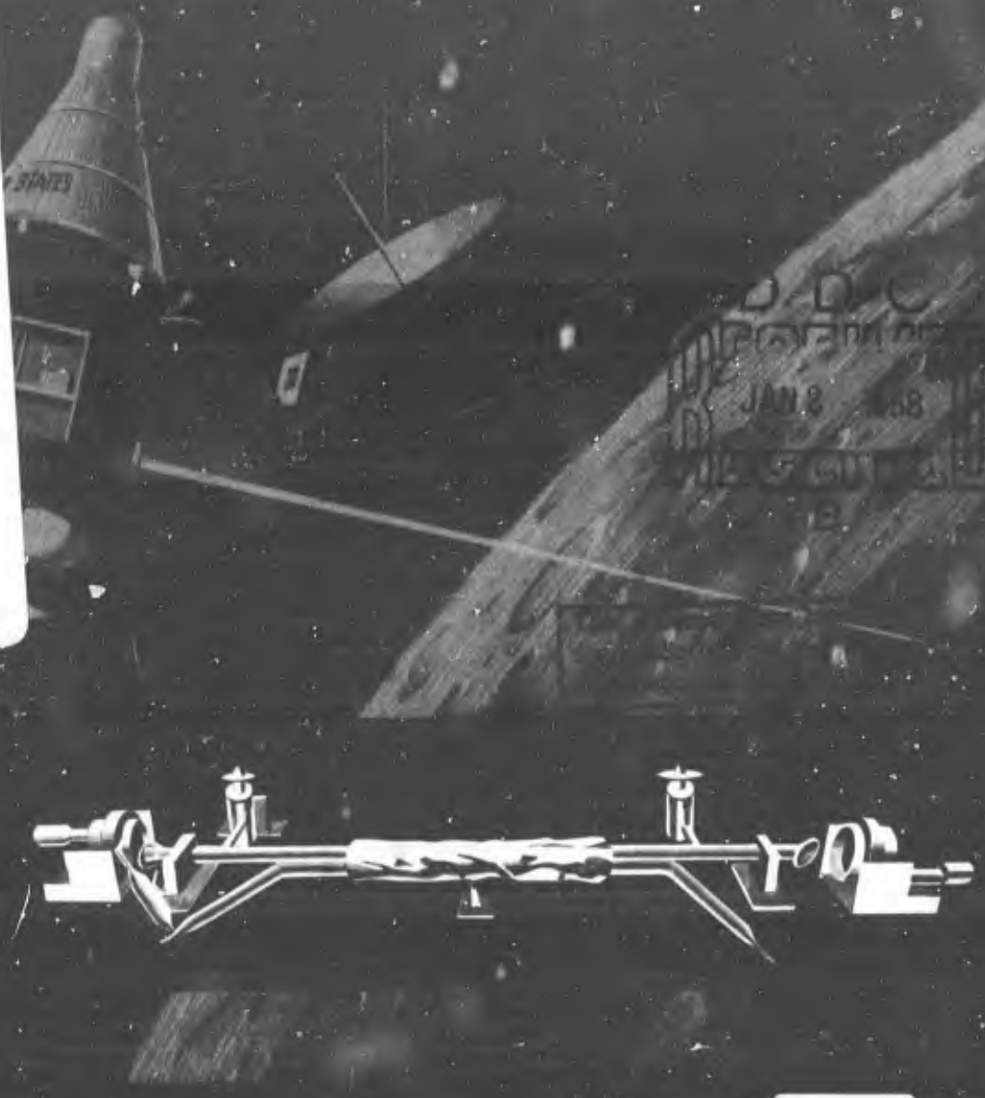
OAR 67-006

OAR progress '66-'67



OFFICE OF AEROSPACE RESEARCH ★ UNITED STATES AIR FORCE

OAR PROGRESS '66-'67

OFFICE OF AEROSPACE RESEARCH
United States Air Force

Arlington, Virginia

FOREWORD

The capability of the Air Force to accomplish its mission is vitally affected by technological change. This fact acquires even greater emphasis as we look to the future. Since the character of technological change is shaped by the application of scientific knowledge gained through basic research, it is mandatory that the Air Force pursue vigorous and dynamic research programs that are relevant to both its current and its future needs.

Seeking and disseminating new scientific knowledge is the mission of the Office of Aerospace Research, the research agency of the Air Force. To accomplish this mission, OAR scientists and engineers are working in many disciplines that were unknown just a few years ago. Many of the problems under attack did not even exist at that time, nor did the language with which to describe them.

Since research results become valuable only when made known to those who can use them, this publication is designed primarily to acquaint those of you who are engaged in research and development, both inside and outside the Government, with some of the highlights of OAR research progress during FY 66 and FY 67. The secondary objective of this publication is to reveal some of the resources and significant aspects of management which helped make this progress possible. Parenthetically, I might add that OAR welcomes your comments and inquiries with regard to any of the research described herein. Only in this manner can we be assured that our mission of "coupling"--the transfer of OAR research results to potential users, and the resultant feedback to OAR--is being achieved.

The research projects that OAR supports often open vast new areas of investigation. Herein lies a reminder that, while research can be programmed, its discoveries and significant breakthroughs cannot. Nevertheless, OAR research has continually yielded rich returns directly along lines of Air Force interest. By stressing relevance to Air Force needs, our research will continue to find solutions for current Air Force problems, and develop viable bases for future Air Force technologies.

I have continually sought to stimulate OAR researchers to conduct their work in a context of potential "application." I have also encouraged our scientists, engineers, and managers to visit other Government organizations with which we share common aims so that, through personal contact as well as through the technical literature, we may maintain a continual, up-to-date awareness of the technical problems to which our research may be applied.

During the past 2 years, my staff and I have briefed more than 4,000 potential users of our research products on the work we are doing. Those briefed have included personnel of all major air commands, elements of the Army and Navy, the Advanced Research Projects Agency, the National Aeronautics and Space Administration, and the National Science Foundation. We, in turn, have been made aware of the numerous technical and operational problems, the solution of which calls for our continued research.

With this in mind, the Office of Aerospace Research stands ready to serve all those Air Force and other Government organizations which have specific problems requiring OAR research. In particular, through this research-application teamwork, we can assure that OAR research progress will be transmuted into significant Air Force capabilities.

Ernest A. Pinson

ERNEST A. PINSON
Major General, USAF
Commander

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OAR COMPLEX

The Office of Aerospace Research is composed of the Headquarters and 10 subordinate units, 5 of which are major research organizations, 2 predominantly research-supporting units, and 3 field liaison offices. The major research organizations are the Air Force Cambridge Research Laboratories (AFCRL), the Air Force Office of Scientific Research (AFOSR), the Aerospace Research Laboratories (ARL), the Frank J. Seiler Research Laboratory (FJSRL), and the Office of Research Analyses (ORA). The research-supporting units are the European Office of Aerospace Research (EOAR), and the Latin American Office of Aerospace Research (LAOAR). The field liaison offices are the Patrick Field Office (PFOAR), the Los Angeles Field Office (LOOAR), and the Vandenberg Field Office (VFOAR). Of these 10 units, 8 are in the continental United States, and the remaining 2 are in Belgium and Brazil.

HQ OFFICE OF
AEROSPACE RESEARCH
Arlington, Va.

Manages the conduct and support of research in those areas which offer the greatest potential for providing new knowledge essential to the continued superiority of the Air Force operational capability. Also manages the conduct and support of specifically assigned exploratory-development efforts.

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. Hanscom Field, Bedford, Mass.

Conducts research in the environmental, engineering and physical sciences, and does exploratory-development work in environment. Contracts for research which closely supports and extends in-house efforts.

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Arlington, Va.

Supports programs, through contracts and grants, of extramural research designed to provide new scientific knowledge and understanding. Areas of research include the physical, engineering, environmental and life sciences.

AEROSPACE RESEARCH LABORATORIES
Wright-Patterson Air Force Base, Ohio

Conducts research in the physical and engineering sciences, and contracts for research which closely supports and extends in-house efforts.

THE FRANK J. SEILER RESEARCH LABORATORY
USAF Academy, Colo.

Conducts research in mechanics, the mathematical sciences and chemistry.

OFFICE OF RESEARCH ANALYSES
Holloman Air Force Base, N. Mex.

Conducts studies to evaluate proposed Air Force systems, to perceive Air Force research opportunities and applications, and to identify future Air Force missions. Provides consultant services to other Air Force organizations as requested.

EUROPEAN OFFICE OF AEROSPACE RESEARCH
Brussels, Belgium

Responsible for the administration of OAR contracts and grants in Free Europe, the Near East, and Africa.

LATIN AMERICAN OFFICE OF AEROSPACE RESEARCH
Rio de Janeiro, Brazil

Administers research efforts in South America.

PATRICK FIELD OFFICE
Patrick Air Force Base, Fla.

LOS ANGELES FIELD OFFICE
Los Angeles, Calif.

VANDENBERG FIELD OFFICE
Vandenberg Air Force Base, Calif.

The three field offices above support the aerospace research effort by maintaining liaison among the scientists, the launch teams, and the contractors. As a result, small scientific experiments are installed on rockets fired for other purposes, thus insuring that the Air Force receives maximum pay-load utilization.

SCIENTIFIC ADVISORY GROUP

The OAR Scientific Advisory Group is a key element in helping OAR develop and maintain an effective research program for the Air Force. The Group, actively associated with OAR in its planning activities, advises the Commander of OAR as to the nation's capability in science, and identifies trends and emerging potentials in areas of science that could afford the Air Force an improved capability. The OAR research program is reviewed on a continuing basis.

Members of the OAR Scientific Advisory Group also act as Boards of Visitors to the OAR laboratories and to AFOSR. In this capacity, they aid the Commander of OAR in evaluating the effectiveness of each organization to make contributions to science of interest to the Air Force and recommend measures to enhance this effectiveness. The members also act as advisors to each of the OAR laboratories and to AFOSR.

CHAIRMAN:

Dr. Joseph Kaplan
Professor of Physics
University of California

VICE CHAIRMAN:

Dr. Launor F. Carter
Senior Vice President
and Director of Advanced
Technology and Research
Systems Development Corporation

Dr. John P. Howe
Director, Department of
Engineering Physics
Cornell University

Dr. Mark Kac
Professor of Mathematics
The Rockefeller Institute

Dr. Carl Kaplan
Research Fellow, Department of
Mechanics
The Johns Hopkins University

Dr. William W. Kellogg
Director, Laboratory of
Atmospheric Sciences
National Center for
Atmospheric Research

Dr. Nathan L. Krisberg
Director, Engineering, Missiles and
Information Systems Division
The Boeing Company

Dr. David B. Langmuir
Director, Physical Research Center
TRW Systems Group

Dr. Gerald M. McDonnel
Associate Professor of Radiology
The Center for the Health Sciences
University of California at Los Angeles

Dr. Elliott W. Montroll
Einstein Professor of Physics
University of Rochester

Dr. Stuart A. Rice
Director, Franck Institute
University of Chicago

Dr. Leonard I. Schiff
Professor and Executive Head,
Department of Physics
Stanford University

Dr. Frederick E. Seitz
President
National Academy of Sciences

FINANCIAL RESOURCES

Management

For all years, from its original establishment through Fiscal Year 1967, OAR is accountable for the following funds:

Source	Millions of Dollars
Air Force	$1,019*
Advanced Research Projects Agency	119
Grand Total	$1,138

In Fiscal Years 1966 and 1967, OAR made the following distribution of funds made available to it by the Air Force and the Advanced Research Projects Agency:

AIR FORCE FUNDS	Millions of Dollars FY 1966	FY 1967
Defense Research Sciences	$ 84.4	$ 88.6**
Environment	10.5	13.1
Aerospace Research Support Program	11.7	11.0
Laboratory Directors' Funds	2.5	2.0
Command Management Funds	2.7	3.0
RAND	15.0	15.0
ANSER	1.3	1.3
Reimbursable Funds	5.9	2.6
Subtotal, Air Force	134.0	136.6
ADVANCED RESEARCH PROJECTS AGENCY FUNDS	16.0	16.6
Grand Total	$150.0	$153.2**

The acquisition cost of real property, including land, buildings, and improvements, and of equipment on hand at the major OAR organizations at the end of Fiscal Year 1967 is shown below:

	Millions
Real Property	$27.2
Equipment	42.3

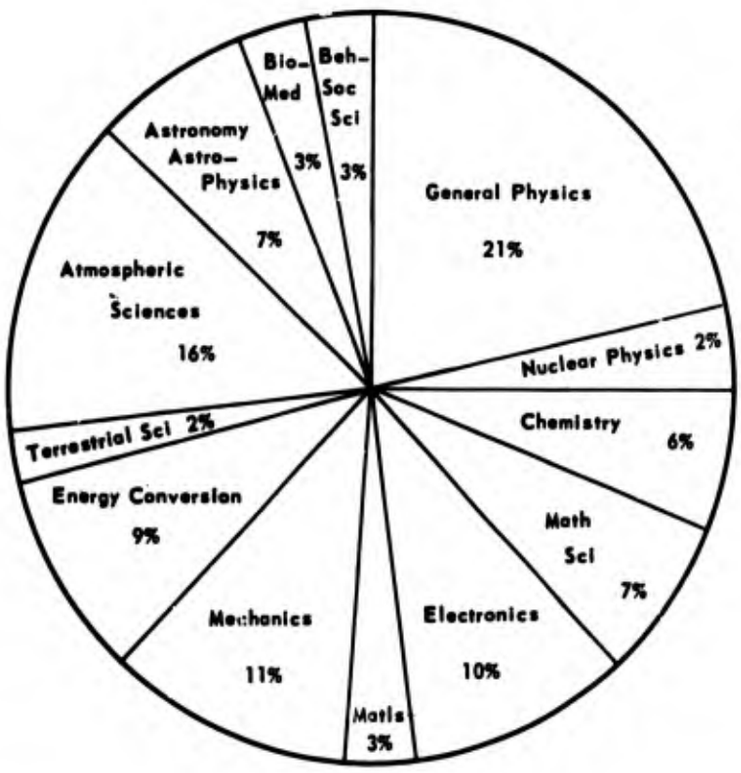
The Defense Research Sciences constitute the complete research program for the United States Air Force, while the Environment Program covers Exploratory-Development efforts in Environment only. Aerospace Research Support funds provide the hardware and payload buildup for aerospace experiments conducted for both the Office of Aerospace Research and the Air Force Systems Command. The Laboratory Directors' funds provide a source of dollars, largely unrestricted in application, with which an individual director can initiate new work in

** Includes reimbursable funds in the amount of $53 million for work for other agencies, including the National Aeronautics and Space Administration and the Defense Atomic Support Agency.*

*** Includes $5.3 million of Project THEMIS funds.*

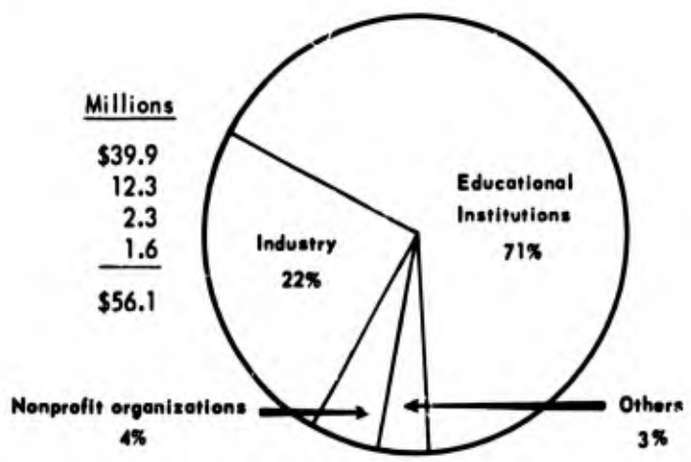
his organization's area of interest. Command Management funds cover the operating expenses of the Headquarters and the various field offices.

In Fiscal Year 1967, the OAR basic-research (Defense Research Sciences) funds were distributed as shown in the following figure. The FY 1966 distribution was quite similar.



The OAR research and exploratory-development program includes an in-house research program and a complementary program of research grants and contracts. In basic research alone, for FY 1966, OAR obligated $58.6 million for grant and contract research by educational institutions, industry, nonprofit organizations, and others. For FY 1967, $56.1 million were obligated by grants and contracts in basic research to these same performers. The FY 1967 distribution was as follows:

	Millions
Educational Institutions	$39.9
Industry	12.3
Nonprofit Organizations	2.3
Others	1.6
Total	$56.1



FUNDING RESEARCH IN FOREIGN COUNTRIES

OAR is successfully offsetting adverse effects upon the Nation's balance of payments of overseas research sponsored by the United States Air Force. The dollar outflow for research has been reduced substantially during the last three fiscal years. This was accomplished without sacrificing the quality or number of essential overseas research projects.

To minimize the balance-of-payments impact of its sponsored overseas research, OAR launched a four-pronged attack to allow unique foreign-science projects to contribute to ongoing Air Force programs without weakening the dollar.

OAR has expanded its cost-sharing arrangements with foreign scientists and educational institutions. As a result, the Air Force bears approximately 41% of the cost of its overseas research, while 59% of the cost of this overseas research is borne by foreign institutions. Through this cost sharing, the Air Force obtained a $13.3-million world-wide research and exploratory-development program in FY 1966 and an $11.2-million program in FY 1967 for a direct investment of approximately $5.5 million and $4.3 million in FY 1966 and FY 1967, respectively.

OAR used approximately $500,000 in FY 1966 and $600,000 in FY 1967 in U.S.-owned foreign excess currencies to pay a portion of each year's direct investment. These currencies, excess to U.S. needs in certain countries, were purchased by U.S. disbursing activities with Air Force appropriations.

Through the co-operation of the Office of Barter and Stockpiling, Foreign Agriculture Service, and of the U.S. Department of Agriculture, OAR obtained an allotment in surplus commodities for barter. As part of the sales proceeds of these commodities, $3.0 million in FY 1966 and $2.5 million in FY 1967 were used to cover the European grant and contract payments, and the Commodity Credit Corporation was reimbursed accordingly with appropriated dollars; that is, these barter funds were included within OAR's regular appropriated fund ceiling.

By encouraging foreign grantees and contractors to purchase U.S.-manufactured scientific equipment and supplies, and to travel by United States flag carriers, OAR produced a dollar inflow of $900,000 during Fiscal Year 1966, and $530,000 during Fiscal Year 1967.

In summary, the net dollar outflow was $1.1 million and $.7 million, respectively, for FY's 1966 and 1967. This outflow obtained a foreign research program in FY 1966 of $13.3 million, and in FY 1967 of $11.2 million. None of the dollar outflow was in Europe.

Actual obligations by country for the basic-research portion of the over-all OAR foreign research and exploratory-development program during Fiscal Years 1966 and 1967 were as follows:

	Thousands of dollars			Thousands of dollars	
	FY 1966	FY 1967		FY 1966	FY 1967
Argentina	$ 71	$ 10	Israel	$398	$531
Australia	238	141	Italy	174	212
Austria	81	64	Jamaica	45	6
Belgium	136	220	Japan	31	42
Bolivia	87	-	Korea	6	7
Brazil	9	74	Lebanon	34	-
Canada	826	365	Netherlands	33	-
Chile	76	33	New Zealand	-	73
Denmark	3	1	Norway	33	-
Finland	43	10	Peru	55	30
France	182	73	Philippines	-	24
Germany	76	91	Spain	32	41
Greece	14	-	Sweden	140	143
Ireland	14	53	Switzerland	-	10
			Uganda	15	-
			United Kingdom	353	503
			Uruguay	20	27

THE OAR MANAGEMENT AND SCIENTIFIC INFORMATION SYSTEM (MASIS)

The effectiveness of management policies within the Office of Aerospace Research is a prime consideration at all levels where resources are allocated and managed. Because the main function of OAR is research, the effectiveness of management policies is related directly to the work being done by the individual scientist on his particular research effort. Several thousand research efforts are being actively conducted at any one time, either at laboratories operated by the Command, or under funding support through its contract-and-grant program. By mechanizing available data, describing research at the individual-research-effort level, and providing for retrieval of that information in consonance with the terms used by the individual managers in evaluating their efforts, the OAR Management and Scientific Information System (MASIS) transforms data into useful information for the people of OAR and higher headquarters.

For example, the manager of a large research effort is able to address himself to this question--"What research is being done in my area, irrespective of fund source or budget program classification?" Managers of research-program areas are able to examine recapitulations of the aggregation of work units supported by their programs or learn the status of individual procurement actions. These status reports are available to procurement offices to recap their workload. With the completion of the research, reports encompassing the results of that research are identified in the data base.

It is obvious that the transition from data to information cannot be accomplished without study and analysis on the part of the human element. Still, data fed into the MASIS must be accurate and be made available in a timely, meaningful fashion. Even as an evolving data-processing system, it must nevertheless aim at continually improving its utilization of data-processing techniques so as to more vigorously support and enhance research-management effectiveness within the Command.

HUMAN RESOURCES

PEOPLE

The success of the Office of Aerospace Research depends upon the quality of its personnel. To keep pace in this age of exponentially increasing scientific knowledge, OAR must be able to attract and hold intelligent, educated, highly motivated people--individuals of ambition, drive and initiative--and to channel their talents toward the accomplishment of Air Force research objectives.

Strength

The personnel strength of OAR is 1,947. This force is composed of 311 officers, 1,430 civilians, and 206 airmen. The greatest portion of OAR's manpower is found in three organizations--AFCRL, AFOSR, and ARL--which conduct or monitor the majority of the OAR research programs.

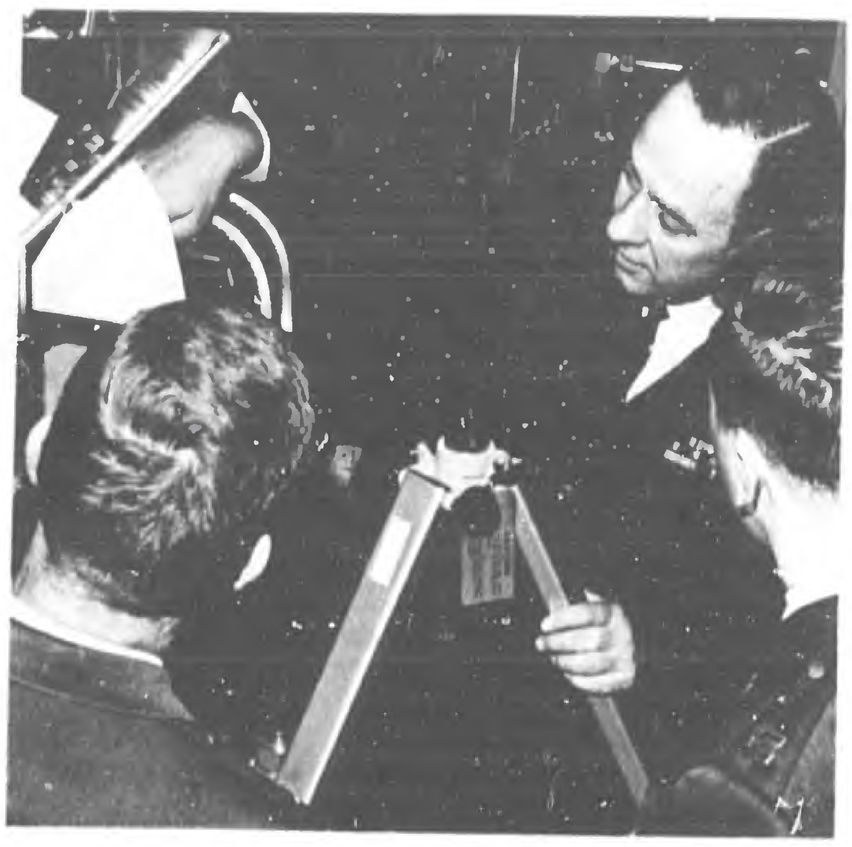
	MILITARY	CIVILIAN	TOTAL
AFCRL	191	973	1,164
ARL	84	241	325
AFOSR	32	111	143

Education

The search for new knowledge that is inherent in the OAR mission demands a high level of educational attainment and research experience. About 48% of the people in OAR are assigned to professional scientific and engineering duties. The educational status of these professionals is considered excellent.

MILITARY - 259		CIVILIAN - 684	
Ph.D.	15%	Ph.D.	29.1%
M.S.	71% *	M.S.	31.1%
B.S.	14%	B.S.	31.6%

** 12% of these officers have an additional 30 S.H. toward their doctoral degree.*



The OAR Five Year Plan looks forward to increasing the doctoral-degree level of the scientific and engineering work force. The objective is 33% for the military and 40% for civilians. OAR urges its people to further their training and to keep current in their specialties through study and research at institutions of higher learning.

To insure the quality of its professional force, OAR expends considerable time and effort on selecting the right people for the right jobs. This matching of men to jobs, for the military and civilians alike, keeps a sharp focus on professional talents and specialties, and on a balanced staff of professional scientists and engineers on the one hand and their supporting technicians on the other.

To acquaint the thousands of young ROTC science and engineering students in colleges and universities throughout the country with the Air Force research program, OAR recently published the brochure, Research Opportunities for Air Force Officers. This brochure emphasizes the importance of postgraduate study, and shows how the Air Force can utilize the talents of these students to further its mission. The publication also describes how young scientists and engineers already serving as Air Force officers may apply for advanced-degree work while on active duty.

During FY 1966, an OAR Postdoctoral Research Associateship Program, administered by the National Academy of Sciences - National Research Council, was inaugurated to give promising young scientists an opportunity to work in OAR laboratories. In FY 1967, arrangements were made to extend this Program to senior scientists of the Free World. To assist in recruiting the best talent available, more than 2,500 brochures on the Program were sent to leading professional personnel of institutions which grant advanced degrees and to publishers of professional journals.

RECOGNITION OF EFFORT

DECORATIONS AND AWARDS

Air Force Outstanding Unit Award

CITATION TO ACCOMPANY THE AWARD OF
THE AIR FORCE OUTSTANDING UNIT AWARD
TO
OFFICE OF AEROSPACE RESEARCH

The Office of Aerospace Research distinguished itself by exceptionally meritorious service in support of military operations, from 1 April 1964 to 31 March 1966. During this period, the personnel of the Office of Aerospace Research conducted a vigorous and dynamic research program which resulted in a vastly improved research capability to meet the technological requirements of the Air Force in the year ahead. The distinctive accomplishments of the members of the Office of Aerospace Research have contributed significantly to the defense of the United States, and reflect great credit upon themselves and the United States Air Force.

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Legion of Merit FY 66

AWARDED for exceptionally meritorious conduct in the performance of outstanding service to the United States.

COLONEL ROBERT E. FONTANA, former Commander, Aerospace Research Laboratories, OAR. For his contributions in the furtherance of the Nation's scientific and technological progress.

COLONEL JACK L. DEETS, former Deputy Executive Director, Air Force Office of Scientific Research, OAR, and now Commander, EOAR. For his efforts in furthering an outstanding basic-research program for the Air Force and ensuring a sound investment of Government funds.

Legion of Merit FY 67

COLONEL JOHN R. FOWLER, former Assistant Deputy Chief of Staff, Plans and Programs, Hq OAR. For his outstanding service in furthering the effectiveness and success of the USAF basic-research program.

LIEUTENANT COLONEL IRA H. S. MCMANN, former Deputy Chief of Staff, Financial Programs, Hq OAR. For his significant achievements in managing the financial programs of the Office of Aerospace Research which contributed greatly to the effectiveness of the USAF basic-research program.

USAF Research and Development Award FY 66

FOR outstanding contributions in scientific management, and administrative, technical, or operational activities of exceptional value to the USAF Research and Development Program.

MAJOR ROBERT R. DETWEILER, formerly with Aerospace Research Laboratories, OAR, now at Air Command and Staff College. For his outstanding research achievements in the field of solid-state physics.

CAPTAIN JAMES T. NEAL, Air Force Cambridge Research Laboratories, OAR. For his outstanding and significant contribution in the field of geology in determining the geological nature of playas (natural dry lake beds).

USAF Research and Development Award FY 67

LIEUTENANT COLONEL JOSEPH W. CONNOLLY, Aerospace Research Laboratories, OAR. For his outstanding research achievements in the field of inorganic chemistry.

CAPTAIN WILLIAM B. GOGGINS, JR., Air Force Cambridge Research Laboratories, OAR. For his outstanding and very significant research contributions in the field of microwave physics.

CAPTAIN JOHN F. SCHAEFER, Frank J. Seiler Research Laboratory, OAR. For his outstanding and significant research contributions in the field of automatic controls for aerospace vehicles.

DR. KENT J. EISENTRAUT, formerly assigned to the Aerospace Research Laboratories as a first lieutenant, now working in the same laboratory in a civilian capacity. For his outstanding research achievements in the field of inorganic chemistry.

FIRST LIEUTENANT CHARLES S. SPRINGER, JR., Aerospace Research Laboratories, OAR. For his outstanding research achievements in the field of inorganic chemistry.

Goddard Award FY 66

DR. HANS J. P. von OHAIN, Chief Scientist, Aerospace Research Laboratories, OAR. Honorarium of $5,000, certificate and medal from the American Institute of Aeronautics and Astronautics for his outstanding contribution to the first successful application of turbojet propulsion to aircraft.

Exceptional Civilian Service Award FY 66

DR. HARRY A. LIPSITT, Aerospace Research Laboratories, OAR. For his exceptionally outstanding leadership and contributions in the science of metallurgy.

Exceptional Civilian Service Award FY 67

DR. ROSCOE H. MILLS, Aerospace Research Laboratories, OAR. For his distinguished career from 1939 through 1966, and his leadership in hypersonic research.

DR. HANS E. HINTEREGGER, Air Force Cambridge Research Laboratories, OAR. For his pioneer research in solar extreme ultraviolet radiation.

Air Force Association Award FY 66

CAPTAIN LAWRENCE SCHROEDER and DR. WILBUR L. HANKEY, Aerospace Research Laboratories, OAR, received the AFA Aerospace Education Foundation Award of $300 and an engraved plaque from MR. EARL N. PARKER for an outstanding paper they co-authored.

Patricia Kayes Glass Award FY 67

MRS. RITA C. SAGALYN, Air Force Cambridge Research Laboratories, OAR. For her contributions as a woman scientist in designing a spacecraft attitude-sensing and control system.

Airman's Medal FY 67

FIRST LIEUTENANT RICHARD S. WILLIAMS, JR., Air Force Cambridge Research Laboratories, OAR. For heroism involving voluntary risk of life at Cape Newagen, Maine on 11 July 1966. With complete disregard for his own safety, Lieutenant Williams launched a rowboat at night into a rough sea, and located and rescued 3 college students whose own boat had capsized.

LOGISTICS

OAR seeks to produce an environment conducive to the responsive support of the research mission so as to relieve the scientist of the irritants of logistics administration. This is to avoid a repetition of past nonresponsive logistics support which has had a detrimental impact on the conduct of reseach in the in-house laboratories. Through critical self-analysis and imaginative logistics-management concepts, OAR aims to determinedly identify and resolve the many problems generated by the incompatibility of standard support systems and the unorthodox demands of basic research.

In the procurement area, OAR has successfully promoted a program to offset the impact upon the Nation's international balance of payments resulting from OAR's support of essential research in foreign countries. This has been accomplished through: the intensified negotiation of cost-shared research agreements with foreign scientists and educational institutions; the establishment of a program to encourage the purchase of U.S.-manufactured equipment and supplies by our foreign contractors and grantees; the payment of our grants and contracts with U.S.-owned foreign excess currencies; an arrangement to cover contract and grant payments with U.S. dollar proceeds from the sale, in world markets, of $9,050,000 in surplus agricultural commodities; and provision for foreign grantee and contractor travel on U.S. flag carriers. The Directorate of Procurement has increased to 6 the number of Secretary of the Air Force approved "Class Determinations and Findings" authorizing the negotiation of contracts that now cover virtually all of OAR's requirements in the areas of research, laboratory logistical support, laboratory directors' fund, exploratory development, sounding-rocket systems, research- and experiment-carrying satellites, and scientific-payload programs. This flexibility eliminates the requirement to process an individual "Determination and Findings" for each procurement action, resulting in a significant resource savings of man-hours and dollars. OAR has also instituted a successful program to obtain agreements with universities to use predetermined overhead rates in order to permit the prompt closing out of completed contracts. Further progress has been made to obtain changes to procurement regulations and directives and to introduce innovations that provide greater flexibility and a more efficient logistics system in support of research.

In the supply-support area, with the approval of Hq USAF, OAR logisticians have developed a supply system which complements the USAF Standard Base Level Supply System and, at the same time, is sufficiently flexible to satisfy the unusual support requirements generated by basic research. OAR will use the standard supply system for obtaining standard, stock-listed items and for routine accounting and reporting, but will bypass the standard system to obtain nonstandard, nonstock-listed items which do not lend themselves to efficient and effective computer processing. Although the authority and responsibility for determination of requirements will be placed on the scientist, the OAR supply system will relieve him of many routine logistics actions.

The OAR Facilities Program has been directed toward the support of strong, modern, and competent in-house laboratories. Recent austere programs throughout the Department of Defense mark a continued downward trend in the approval and construction of new facilities. To offset the effects of this trend, OAR Military Construction submissions have been critically selected and contain minimum essential requirements. A solar vacuum telescope costing 3.2 million dollars is the only major facility currently under construction. This facility will be completed in early 1968. OAR's future program, for fiscal years 1968 to 1973, provides for facilities costing over 7.2 million dollars, including 3 laboratories and a library addition. The construction program, in facilitating the achievement of research results, necessarily embraces an important segment of the over-

all research program.

For the fourth successive year, since the inception of the formal USAF Cost Reduction Program, OAR has made significant contributions to this vital Program. This is a particularly noteworthy accomplishment in view of the constant increase in goals since Fiscal Year 1964 and the problems in relating basic-research activity to the Program.

From the very first day of its establishment, Hq OAR has been housed in old temporary buildings in downtown Washington, D.C. Its recent move to the Architect Building, 1400 Wilson Boulevard, Arlington, Virginia, has permitted Hq OAR (and AFOSR) to eliminate marginal working conditions and to provide a local atmosphere far more conducive to the efficient conduct of important Air Force scientific business. (See photo)

FUTURE OUTLOOK

The weapon systems of the future will be dependent on the research being done today and, in many cases, will be dictated by the results of this research. Consequently, it is essential that systematic planning in substantive and fiscal terms be intensified, that long-range goals be identified, and that anticipated programs be formulated to meet these goals. To accomplish this, OAR has established a Five Year Plan which sets forth Organization and Technical Objectives, describes courses of action for their accomplishment, and injects studied estimates of the required resources. Major OAR objectives are:

Corporate and Organizational Objectives

Enlarge OAR's contribution to, and participation in, planning for the future Air Force. This will be accomplished by developing within Air Force decision-making channels a greater understanding of, and appreciation for, the products of science, and Air Force involvement in science--and by increasing the use of in-house scientific counsel by Air Force decision makers.

Improve and strengthen the in-house laboratories to make them a more effective base for the over-all OAR effort.

Make laboratory-resources management more flexible by persuading higher authority to introduce facility-construction procedures more compatible with research activities than current military-construction procedures. An included objective is to obtain authority to use research funds for laboratory construction.

Fully develop and refine methods for effectively disseminating research results and new ideas to agencies which can apply them to advance Air Force technology. This would include demonstrations of possible applications in addition to written and verbal reporting.

Continue to study various organizational relationships to improve or amplify OAR effectiveness and to make OAR contributions to the Air Force more apparent.

Strengthen and further develop existing relationships between OAR and AFSC at all levels.

Scientific and Technical Objectives

Achieve greater understanding of the phenomena under investigation.

Encourage Air Force research people to greatly enhance their knowledge and understanding in the various scientific fields as well as their awareness of scientific states-of-the-art so they can provide the Air Force with its own expert scientific counsel.

Develop new techniques and obtain new knowledge directed toward solving specific Air Force problems.

Continue to accomplish research for other agencies (upon their request) in those areas in which a unique OAR research capability exists.

Improve those functions and techniques which support research and exploratory development.

In facing the future, the character and evolution of OAR itself must be considered. Present plans call for the organizational structure of OAR to remain essentially the same as at present. AFOSR, AFCRL, FJSRL, ARL, and ORA will continue as distinct, but co-operating, subordinate units.

Major emphasis in the future will be in the Defense Research Sciences including the new University Program (Project THEMIS) whereby, commencing in Fiscal Year 1967, funds will be assigned to expand the defense research base in eligible and interested universities not now heavily supported by the Federal Government. Emphasis at AFCRL will continue in the geophysical and environmental sciences. ARL will carry on as a laboratory for the physical and engineering sciences, with some expansion in the latter. FJSRL will remain in chemistry, mechanics and mathematical sciences, with new programs in strategic theory and international

politics. ORA will become increasingly active in the mathematical sciences. At AFOSR, about 20% of its future efforts will consist of "supporting research" identifiable with known Air Force technological barriers. About 70% will be "pioneering research" aimed at developing new or emerging fields of science with probable Air Force significance. The remaining 10% "connecting research" will maintain Air Force contact with broad areas of science supported largely by non-Air Force agencies.

RESEARCH INFORMATION ACTIVITIES

The communication of research findings in a way that is meaningful to potential users continues to present a challenge to OAR ingenuity and, at the same time, offers one of the best opportunities for serving the Air Force.

OAR has continued to strengthen the environment which would permit the more effective exploitation of scientific knowledge by the Air Force. OAR has emphasized the use of science to cope with many of the technical problems arising from our military operations in Vietnam. Meeting these problems has provided OAR with an opportunity to assess its "coupling" program, which has been built up carefully over a period of several years.

The coupling program is an effort to effect an orderly and timely transfer of research results to users, and to promote feedback from users in order to stimulate their assistance in providing direction to OAR research. The program is based on the conviction that information transfer is everybody's job. Thus, OAR is the only DoD research organization that is known to include the responsibility for information transfer in the job descriptions of its scientists and engineers.

The success of the coupling program will be proportional to the emphasis placed on this activity by the managers. The OAR offices responsible for scientific-and-technical-information policies attempt to focus the attention of these managers on the information program. Special offices have also been established to provide emphasis and guidance in information problem areas. In addition, OAR has set up offices in its Headquarters and in its major units to review the products of OAR research and to seek possible applications for them in the Air Force, DoD, and defense-oriented agencies. For example, the Aerospace Research Laboratories (ARL) have established a two-man technical team to insure maximum exploitation of the results of ARL research and of its in-house scientific capabilities. The team devoted much of its attention this year to technical problems arising from requirements in Southeast Asia. Other offices to perform similar functions have also been set up at other OAR organizations.

During the past year, the research-information activities of the Air Force Office of Scientific Research (AFOSR) have been consolidated under the Assistant Executive Director for Research Communications. Under him have been grouped the Information Staff Officer, the Assistant for Research Services, and the Assistant for Research Co-ordination. The Assistant for Research Services is responsible for the co-ordination of symposia and similar activities. The Assistant for Research Co-ordination has dual responsibilities: bringing Air Force problems to the attention of the AFOSR staff as an aid in research planning, and accelerating the application of research results to technology. This grouping of related activities into a single unit has helped to more effectively co-ordinate within AFOSR the procedures whereby AFOSR research progress and achievements are communicated to those outside the Air Force Office of Scientific Research.

The so-called "road shows" are one means by which OAR tries to impart the results of its research to potential users. These visits by OAR technical briefing teams to other agencies serve to inform Air Force technologists of recent Air Force scientific

developments without burdening them with technical reports. The road shows include discussions of those OAR research results which are deemed most likely to be of interest to the particular organizations visited. They also provide feedback opportunities for these organizations to acquaint OAR representatives with their technical problems. In the past two years, OAR road-show teams have visited more than 20 Government agencies and have addressed some 3,500 people, both within and outside the Air Force. These have included the Air Defense Command, the Strategic Air Command, the Tactical Reconnaissance Center, and all laboratories of the Research and Technology Division (now Directorate of Laboratories), AFSC.

The number of OAR scientists who give their time to consulting for the Air Force and to involvement in special Air Force studies has increased significantly. The Air Force Cambridge Research Laboratories (AFCRL) alone provided about 155 such consultations during the past two years. AFCRL has also concluded a formal agreement with the 6th Weather Wing of the Air Weather Service to co-operate in environmental consultations for the developers and operators of aerospace systems.

In order to improve communications between its own scientists and the users of its scientific findings, the Air Force Cambridge Research Laboratories, in 1967, established the AFCRL Environmental Consultation Service. This Service is responsible for applying environmental research results to problems of the Air Force, DoD, and other Government agencies in the terrestrial, atmospheric, and space sciences, and in electromagnetic propagation and plasmas. The Service seeks to encourage increased use by all qualified agencies and their contractors of AFCRL's scientific competence in the solution of planning, design, developmental, and operational problems in the environmental area.

OAR has continued to complement its face-to-face scientific and technical communications with refinement of its publications and announcement media. In the past two years, OAR has published more than 8,000 scientific papers and reports, either in-house or by contract or grant. More than half of these appeared in professional journals where, prior to acceptance for publication, they were subjected to quality review by their authors' scientific peers. In-house technical reports were also given this quality review by the OAR laboratory supervisors prior to publication.

These "primary" publication activities have been supplemented by other efforts to facilitate an awareness of new research results. Improved announcement procedures of the Defense Documentation Center (DDC), and corollary activities of the Federal Clearinghouse for Scientific and Technical Information may permit OAR, in the future, to shift its emphasis from the publication of indexes and bibliographies, which cover the whole spectrum of Air Force research, to the development of more specific methods for the selective announcement of scientific and technical information.

Experiments in selective-dissemination-of-information (SDI) techniques have led to a new approach for announcing research results. SDI uses computers to screen user interest "profiles" and to match the key words expressing the user's technical interests with the key words describing the contents of new technical papers. Each scientist-user whose profile has been matched is notified only concerning those documents which are relevant to his own interests. This SDI technique shows considerable promise for augmenting a necessarily limited library service, for providing a more personalized information transmission mechanism, and for reducing the burden on the scientist and engineer who must often screen the voluminous literature in order to extract a few items relevant to his own interests.

To date, about 200 Air Force scientists and engineers have participated in OAR's experimental SDI program. They have personally received notification concerning all the literature acquired and indexed by the National Aeronautics and Space Administration and the American Institute of Aeronautics and Astronautics. Further, experiments in technical-interest profile construction have been conducted. Lower cost methods

are under study with a view to the development of an expanded system for the selective announcement of new scientific and technical information.

Preparations were under way in Fiscal Year 1967 for the initiation in September 1967 of another experimental information-dissemination program to be sponsored jointly by OAR and the Clearinghouse for Federal Scientific and Technical Information, Department of Commerce. This six-months' trial program has been designed to keep a large sampling of Air Force scientists and engineers abreast of the latest documentation in their fields of interest through the medium of the new biweekly Clearinghouse Announcements in Science and Technology (CAST), which lists (in 65 different subject areas) all unclassified-unlimited Government technical reports as they become available from the CLEARINGHOUSE. Subscribers to the service receive CAST only in their indicated fields of interest and only those reports that they have specifically requested. This trial will provide an opportunity to evaluate a modified SDI program that appears to offer the advantages of selectivity, readability, lower cost, and the comprehensiveness of a large data base.

Since SDI, however, is still in its embryonic stage, OAR must presently rely on its broad-based publications to disseminate information on its planned, current, and completed research to Air Force, DoD, and other Government and non-Government scientists and technologists. Such users run into the thousands, world wide, and receive such OAR publications as the Air Force Research Objectives, the OAR Monthly Report of Research Proposals, the OAR Research Review, the Air Force Research Resumes, the OAR Index of Research Results, the OAR Progress, and others. These recurrent publications contribute effectively to the coupling activities so vital for the exchange of information on Air Force research.

As a further aid to the coupling process, OAR has published the Hq OAR Consolidated Distribution List which has proved to be an outstanding management tool for controlling the distribution of OAR documents. By providing a check against secondary distribution made by organizations receiving OAR publications, it has practically eliminated duplicative distribution and kept waste to a minimum. It has not only contributed to the coupling of OAR researchers and users of OAR research results, but has also encouraged user participation in updating the mechanized OAR distribution list, and increased the users' awareness of OAR publications available to them.

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SCIENTIFIC PROGRESS FY 66

SCIENTIFIC PROGRESS IN FY 66

The brief articles on the following pages describe some of the research accomplished by OAR during Fiscal Year 1966 in areas of significance to the Air Force. The work includes both contributions to basic knowledge and applications of research vital to the steady technological progress of the Air Force. Although these articles treat only a fraction of the research carried out in OAR's own laboratories and in the laboratories of its contractors and grantees, they do provide some idea of the importance, variety and scope of the whole OAR research program. This will be immediately apparent from the various DoD Elements and Subelements (shown below) encompassing OAR's diverse research efforts.

Those desiring additional information on the research accomplished should consult the comprehensive Bibliography following the section on Scientific Progress in FY67.

LABORATORY DIRECTORS' FUND PROGRAM ELEMENT 61430014

DEFENSE RESEARCH SCIENCES PROGRAM ELEMENT 61445014

Subelements:

General Physics	**Mechanics**
Nuclear Physics	**Energy Conversion**
Chemistry	**Atmospheric Sciences**
Mathematical Sciences	**Astronomy and Astrophysics**
Electronics	**Biological and Medical Sciences**
Materials Research	**Behavioral and Social Sciences**

AEROSPACE AVIONICS PROGRAM ELEMENT 62405314

ENVIRONMENT PROGRAM ELEMENT 62405394

GROUND ELECTRONICS PROGRAM ELEMENT 62405454

STUDIES AND ANALYSIS PROGRAM ELEMENT 62410034

EXPLORATORY DEVELOPMENT/DEFENDER PROGRAM ELEMENT 6250301R

ENVIRONMENTAL RESEARCH SUPPORT PROGRAM ELEMENT 65402124

MOLECULAR BEAMS

Two recent AFCRL developments will provide scientists with molecular-beam generators for investigating phenomena previously impossible to study with adequate precision. These new techniques provide high-intensity molecular beams in the critical energy range between 1 and 10 electron volts.

One generator involves an important new idea in the use of a charge-exchange system. For the first time an axial magnetic field is used to guide the neutral plasma to the electrostatic acceleration region. The charge-exchange process then neutralizes about 50 percent of the accelerated ions with little attenuation, and the device can provide a beam of about 10^{14} molecules per square centimeter per second. This is at least 4 orders of magnitude (at 10 electron volts) improvement over other charge-exchange beam generators.

The other generator uses an extremely simple concept. A bullet (sabot) is filled with the gas of interest and sealed with a membrane. This is fired into a vacuum where the bullet is stopped, simultaneously rupturing the membrane. A schematic representation of this system (called the MASS system), is shown in Figure 1. With a .22-caliber rifle, the gas will attain 3 km/sec; the energy, of course, depends on the mass of the particular gas molecule. Light gas guns in hypervelocity ranges can accelerate sabots to 10 km/sec. A design study shows that a flux of 10^{25} particles/cm^2 will be feasible.

The importance of this energy range to the

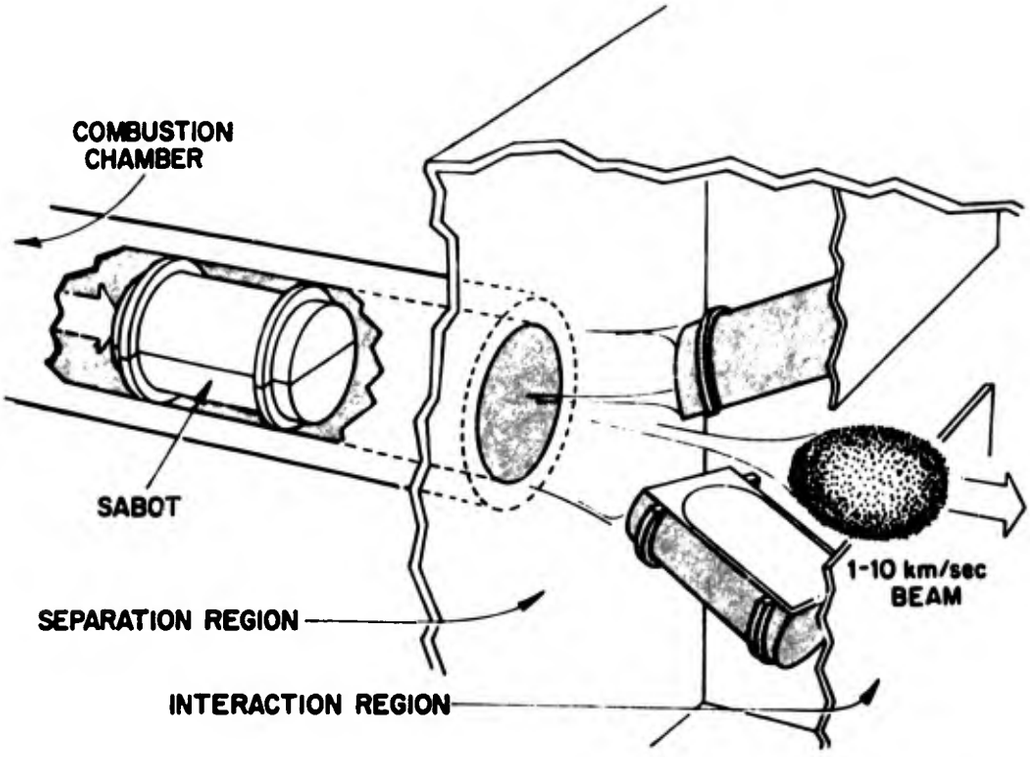

Figure 1. MASS molecular-beam system.

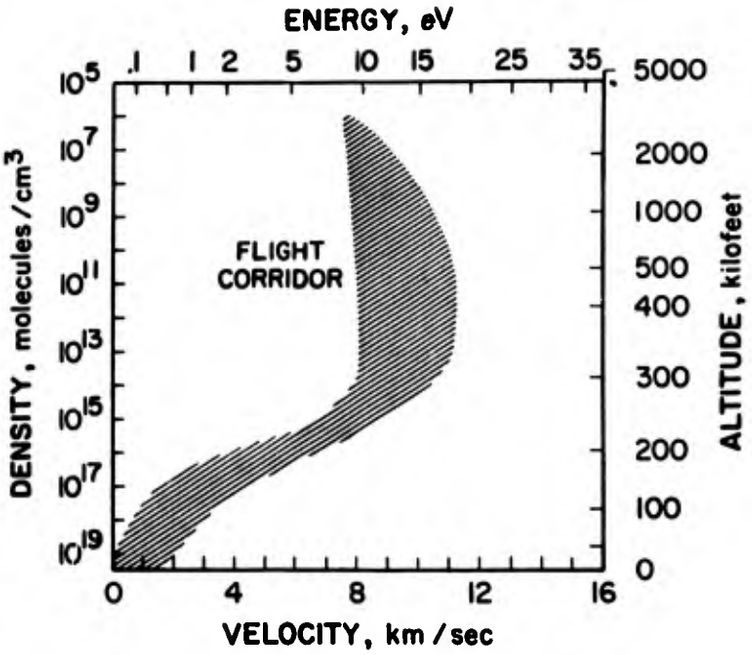

Figure 2. Flight corridor.

Air Force is shown in Figure 2, which represents the so-called flight corridor. The velocities and altitudes represent the physical regime where missiles, satellites, and aircraft interact with the ambient atmosphere. Current techniques to study such phenomena in the laboratory involve primarily shock tubes and huge wind tunnels. Both approaches have limitations, and are often very poor approximations to the conditions of interest. High-intensity molecular beams of the proper energy will permit measurements beyond the capability of other techniques. For example, the effects of hypersonic gas flow on various surfaces, and the basic flow characteristics can be studied more precisely and inexpensively with such molecular beams; and more precise calculations of drag coefficients, decay of satellite orbits, etc., will result from such studies. From a scientific point of view, the energy regime of 1 to 20 electron volts encompasses the binding energy of molecules and, consequently, the activation energy of most chemical reactions.

HUMIDITY ABOVE THE HYGROPAUSE

For several years there has been controversy concerning the amount of distribution of water vapor in the stratosphere. There are diverging theories. One proposes that the moisture in the stratosphere is homogeneously mixed in both time and space, amounting to roughly 2 parts per million by weight of the air. The other suggests that, at least in the 50,000 to 100,000-foot level, the mixing ratio (mass of water vapor to that of dry air) varies, sometimes increasing with altitude. At 100,000 feet, the difference in the amount of water vapor proposed by these 2 theories could mean the difference between an infrared detector receiving a threshold signal from 10 miles or 1,000 miles.

In an effort to resolve the difference between these two theories, and to give Air Force system designers a more solid basis for estimating high-altitude water-vapor amounts, Messrs. N. Sissenwine, D. Grantham, and H. Salmela and Major R. Cowne of AFCRL conducted a year-long program

of monthly stratospheric humidity soundings.

A highly sensitive alpha radiation hygrometer was the key instrument used in the investigation. This frost-point hygrometer was carried aloft by 110-foot-diameter balloons launched from the AFCRL balloon-launch site at Chico, California. Included in the many precautions taken to avoid extraneous water-vapor contamination from the balloons and instrumentation was the reeling down of the sensor package 2,000 feet below the balloon assembly.

Although the results from the program are only preliminary, and should be verified through future experiments, they are considered quite significant. A definite increase in the water-vapor-to-dry-air mixing ratio with altitude was found. However, the increase was less than that previously proposed. Perhaps an even more important finding was a systematic seasonal variation of about 10° C frost point.

Other salient features observed in these soundings were (1) wet and dry layers of 1- to 2-km thickness in the stratosphere, and (2) transport of tropospheric air into the stratosphere through a weakened tropopause. This passage through a mid-latitude tropopause is contrary to the assumption necessary for the "constant-mixing-ratio" theory.

In the 3-km layer just above the tropopause, the mixing ratio was found to decrease one order of magnitude, down to about 3 parts per million. At this level, which has been designated the "hygropause," the frost point reaches a minimum, averaging about -81° C.

The basic characteristics of the hygropause, as related to the frost-point profile, are analogous to those of the tropopause as related to the free-air temperature profile. Above the hygropause, the frost point increases slowly with altitude to about -78° C at 26 km, where the mixing ratio increases also to a value of 17 parts per million.

The ratio of water vapor to dry air cannot increase with altitude indefinitely. To find the altitude where this ratio begins to diminish, a much larger balloon was recently used to carry the sensing system to the 26- to 32-km region. It was revealed that the ratio diminishes at about 27 km with a gradient commensurate with humidities speculated to be present in noctilucent clouds at roughly 80 km. The 26-km altitude level, at which most of the earlier soundings terminated, is, coincidentally, the maximum altitude of penetration into the stratosphere of cumulonimbus clouds, and also the altitude at which nacreous clouds are observed to occur during mountain wave situations.

METALLIC IONS IN THE LOWER IONOSPHERE

During meteor showers, metallic atoms from vaporizing meteors may greatly alter the composition of the lower ionosphere. These metallic atoms are subsequently ionized by the normal photochemical and collisional processes of ionospheric formation. The addition of these ions to the ionosphere may be correlated with increased sporadic E activity. In one series of rocket flights into sporadic-E layers, it was shown that sporadic E was composed entirely of metallic ions.

These are the results and implications of rocket data analyzed by R. S. Narcisi, A. D. Bailey, and L. Della Lucca of AFCRL.

Three papers presented by them at the May 1966 Committee on Space Research (COSPAR) meeting covered different aspects of 2 rocket flights that took place on 16 and 17 November 1965, during the annual Leonid meteor shower. The 2 Nike-Cajun rockets carried unique and highly precise mass spectrometers to sample the composition of the D and lower E regions of the ionosphere. It is in these regions, which extend from about 50 to 110 km, that atmospheric friction heats and vaporizes meteorites. Metallic positive ions of meteoric origin were found to make up a sizable portion of the content of the lower ionosphere.

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During the 1965 Leonid shower, Narcisi, Bailey, and Della Lucca found that, between 85 to 100 km, the positive ions of sodium, magnesium, aluminum, calcium, iron, nickel, and silicon--all of which are substances found in meteorites--constituted 30 to 50 percent of the total ionization, the remainder being ions of nitric oxide and molecular oxygen. In addition, they found that metal-ion concentrations were much lower between 100 and 110 km, the altitude immediately above that where maximum meteor vaporization occurs.

Data from the 17 November flight, made the night after the shower, also proved significant. On this flight, sporadic E layers were sampled by means of a rocket-borne mass spectrometer--the first time such a feat had been accomplished. On the 17 November flight, the two layers of sporadic E that were sampled were found to be composed of the positive ions of iron, magnesium, calcium, and nickel. These, again, are metals found in meteorites.

Although some metallic ions were first detected in the lower ionosphere by other experimenters, the AFCRL scientists were the first to identify the ions of all seven major metals normally found in meteors, and to measure their altitude distributions as well.

An understanding of sporadic E formations will aid in the design of Air Force radio networks to overcome this geophysical interference with radio-frequency communications.

defense research sciences ***general physics***

A NEW INSIGHT INTO THE BEHAVIOR OF FERRIMAGNETIC CRYSTALS

If a ferrimagnetic crystal, such as yttrium iron garnet, is placed in an external magnetic field in an arbitrary position, and energized with microwave energy, it will probably exhibit no magnetic resonance at all. But, if the same crystal is carefully aligned so that the magnetic field attains a certain direction within the lattice as well as having a certain magnitude, then its resonance will be strong. If either the intensity of the magnetic field or the crystal temperature is varied, the resonance disappears. However, a strong magnetic resonance is again obtained by carefully realigning the crystal to compensate for these changes.

Described above are manifestations of magnetocrystalline anisotropy. It is this which causes the magnetic properties of a ferrimagnetic crystal to vary with crystalline direction. This simply means that it is easier to magnetize the crystal in one direction than in another. To obtain maximum magnetic resonance, the alignment of the crystal with the external magnetic field must be extremely precise. Obtaining this single, preferred alignment is, in fact, the key aspect and/or difficulty associated with its use in microwave devices.

When the experimenter sets out to determine the anisotropy properties of a ferrimagnetic crystal, he measures the changes in the external magnetic field required to obtain the magnetic resonance at different crystal orientations. Also, he keeps the temperature and the energizing microwave frequency constant.

Recently, a clearer insight into magnetic resonance in ferrimagnetic crystals has been obtained by Dr. Ernst R. Czerlinsky and Mr. Peter D. Gianino of AFCRL. This insight has resulted in procedures for the utilization of ferrimagnetic materials which do not require 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 the direction of the magnetic field. The precessional frequency of the magnetic vector is basic to the novel procedures

formulated by Czerlinsky and Gianino. The precessional frequency depends on the torques which the magnetic vector experiences, both from the external magnetic field and from the anisotropy field. The latter depends on the direction of the magnetization vector within the lattice. Heretofore it was known that, for one particular direction within the lattice, the anisotropy field is zero. Consequently, temperature changes do not affect the resonance frequency if the external field is aligned in this "singular" direction. Precise crystal orientation was required to guarantee elimination of the temperature effect on magnetic resonance. The studies of Czerlinsky and Gianino have 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 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 validity of the above results for application in microwave devices. In certain planes, deviations up to about 10 degrees from the ideal position of the crystal did not markedly affect the resonance field over a temperature range approximately 30 degrees Kelvin above and below ambient.

This work has application in the optimization of magnetic materials in microwave devices.

general physics

ELECTROPHORETIC AND CATAPHORETIC EFFECTS IN A HELIUM-NEON LASER

When a glow discharge is operated in a mixture of two gases, there is a partial separation of the gases after a period of time under certain conditions. If this effect is due specifically to a drift of one gas towards the cathode, the process is termed cataphoresis. Normally, the gas with the higher ionization probability is selectively driven towards the cathode of the discharge, but exceptions do occur, caused by variations in the electron-collision cross-section functions.

Also, in narrow tubes, the influence of the insulating boundary becomes important. In the case of an infinite plasma, the electron-momentum transfer to the neutral gas is equal and opposite to the ion-momentum transfer. The presence of an insulating boundary requires that the positive-ion and electron currents to the walls be equal. However, the different masses and temperatures of the ions and electrons do not allow the momentum transfers to be balanced. As the ions deliver more momentum to the walls, there is a net unbalanced electron momentum to the gas which results in a force on the gas in the direction cathode to anode. This process, termed electrophoresis, is affected strongly by the discharge-tube radius.

During the past year, the Plasma Physics Research Laboratory of ARL has made measurements on the significance of these processes in discharges in gas mixtures, particularly gas lasers. Research conducted by Dr. Alan Garscadden and associates has determined that electrophoresis and cataphoresis have a considerable influence on laser output and laser noise.

In an He-Ne mixture, neon (which has the lower ionization potential) tends to collect near the cathode end of the tube. For a typical laser configuration in a 1-meter optical cavity, and a discharge-tube capillary of 4-mm internal diameter filled with an initial 4:1 He-Ne mixture at a pressure of 1.5 torr, it required approximately 400 seconds to obtain a partial-pressure equilibrium. This time was estimated by observing the changes in intensity of representative He and Ne lines

after turning on the discharge. Typically, intensity variations of the order of 20 percent were recorded.

Analysis (1) of the properties of fluctuations and moving striations in glow discharges indicated that they should be sensitive to changes in the ionization frequency, and therefore to changes in the partial pressure of the gases. Further evidence of the influence of cataphoresis was therefore obtained by measuring the noise-frequency spectrum of the discharge sidelight as a function of time from the initiation, and as a function of position along the column. It was found that the anode end of the discharge gave increased noise in a band around 220 kHz; near the cathode end, increased noise was noted around 360 kHz. What these results mean physically can be seen in Fig. 1, a rotating-mirror photograph in which the axis of rotation of the mirror was parallel to the discharge axis. It is seen that the discharge supported moving striations appropriate for conditions found at each end of the column. The relative frequencies were in agreement with an approximate analysis (2). The time required to reach a stationary noise spectrum was the same as that required for the spectral intensity changes and for the laser output to reach equilibrium. Thus, the initial gas-filling ratio is not usually that existing in the discharge after a short time. The laser-output beam also showed increased noise at the discharge noise frequencies. In many applications it is important to be able to choose conditions to suppress this additional noise. The theory gives methods and design indications to achieve this aim.

In other experiments (3) made on different gases and gas mixtures, with emphasis on those used in lasers, a number of new phenomena were observed and clarified.

The foregoing work was conducted as part of an over-all research program in phenomena of this type. Electrophoresis plays a part in determining the efficiency of gas lasers, especially high-current ion lasers. Cataphoresis is useful in the purification of mixed gases.

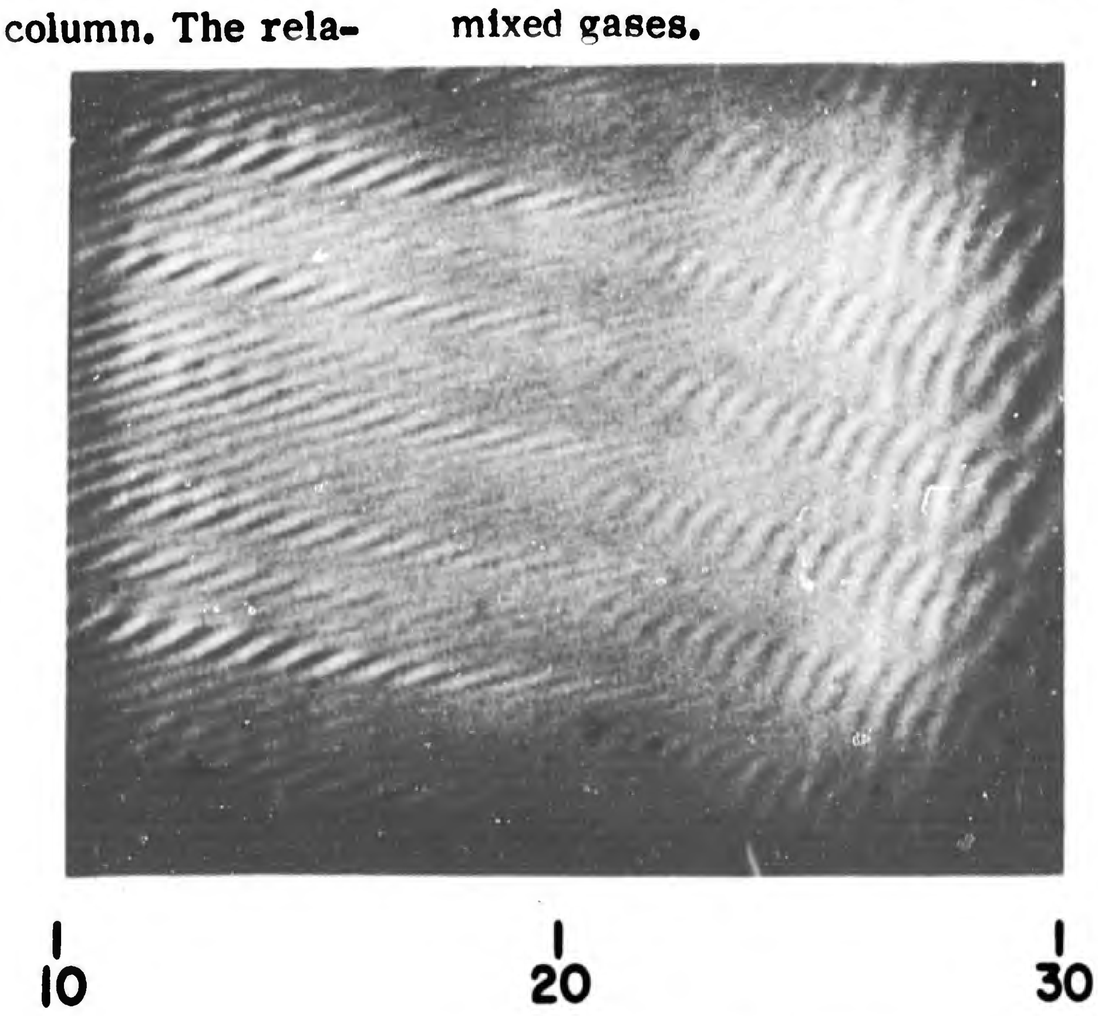


Figure 1.
Smear photograph showing the two types of moving striations in the laser. Cathode end is to the left; time increases downwards. Frequencies are approximately 360 kHz (cathode end) and 240 kHz (anode end). Discharge current is 13.5 ma.

OPOS—STUDY OF THE OPTICAL PROPERTIES OF ORBITING SATELLITES

The spectacular and exceedingly regular changes in the brightness of the early Soviet upper-stage rockets were of common knowledge to the most casual observers of satellites in mid-1958. Equally familiar today is the nearly invariant brightness of the more recent, large Echo balloon satellites. Less commonly observed were unique instances when the brightness of the Sputnik III rocket, 1958 Delta I, was apparently invariant for long arcs across the sky even though its lazy rotation at approximately 3 rev/min about its center of mass was still present. The apparent invariance was due to special geometrical conditions when the amount of sunlight scattered by the elongated cylindrical form of the rocket was nearly constant in the observer's direction despite the rotational motions.

This unusual behavior of the brightness of early satellites, and many other phenomena observed through small telescopes in the course of optical-tracking experiments at ARL, have raised many fundamental questions on the brightness properties of satellites scattering the intense radiation of the sun. What is the dependence of the brightness on phase angle (see Figure 1) to the illuminating sun? What is the dependence on satellite shape, on the nature of the surface finish, on the size, and on the curvature of the reflecting elements? What secular changes in brightness occur due to exposure to the space environment? With applications in mind, one can ask: What are the rates of change of the brightness of orbiting targets when the control of camera shutters might be required to keep the effective exposure within the dynamic range of the film or photoelectronic detector? What excursions of brightness about a mean brightness level should be anticipated in order to allow evaluation of the performance of automatic space-surveillance systems operating at visible wave lengths? Can relationships be found in the pattern of light variations which would characterize a given type of spacecraft without requiring the actual resolution of its shape through the atmosphere?

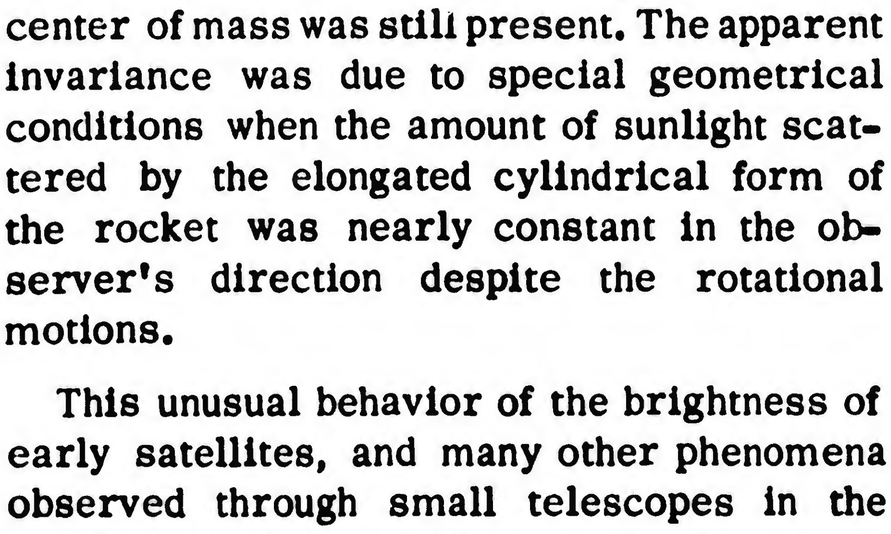


Figure 1. Scattering of sunlight by an orbiting spacecraft. (Drawing courtesy of E. M. Vallerie, III.)

To answer these fundamental physical questions, and to provide a reservoir of data upon which answers to the systems-applications questions can be based, ARL and the Air Force Avionics Laboratory (AFAL) entered a joint research program to conduct photoelectric observations of orbiting spacecraft. This work, begun in 1961, has led to the present ARL program on Optical Properties of Orbiting Satellites (OPOS). In 1962-63, AFAL moved its personnel to New Mexico to bring into operation the Cloudcroft facility. The satellite photometry work was expanded by Messrs. Kenneth E. Kissell and Richard C. Vanderburgh of the General Physics Research Laboratory, ARL.

Figure 2 shows a special multiaxis telescope of 24-inch aperture which was conceived at ARL and placed in operation in 1965, at the ARL Sulphur Grove Field Site near Wright-Patterson Air Force Base, to allow the collection of data from targets at distances up to 25,000 km. This versatile, hand-guided telescope has proven to be of sufficient quality to allow the photographic resolution of low-altitude targets for simul-

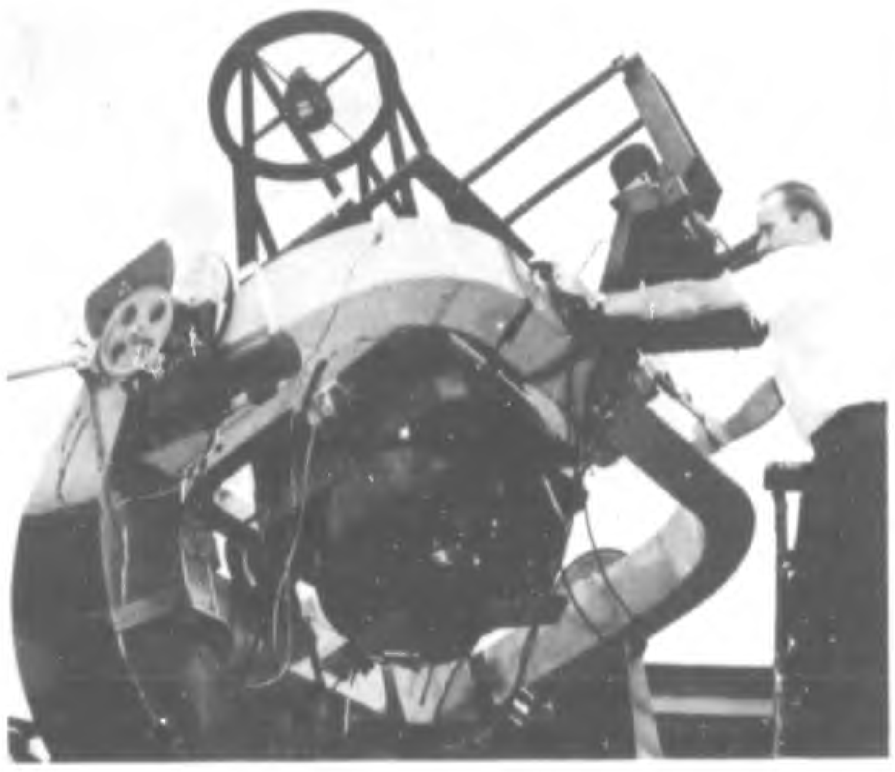


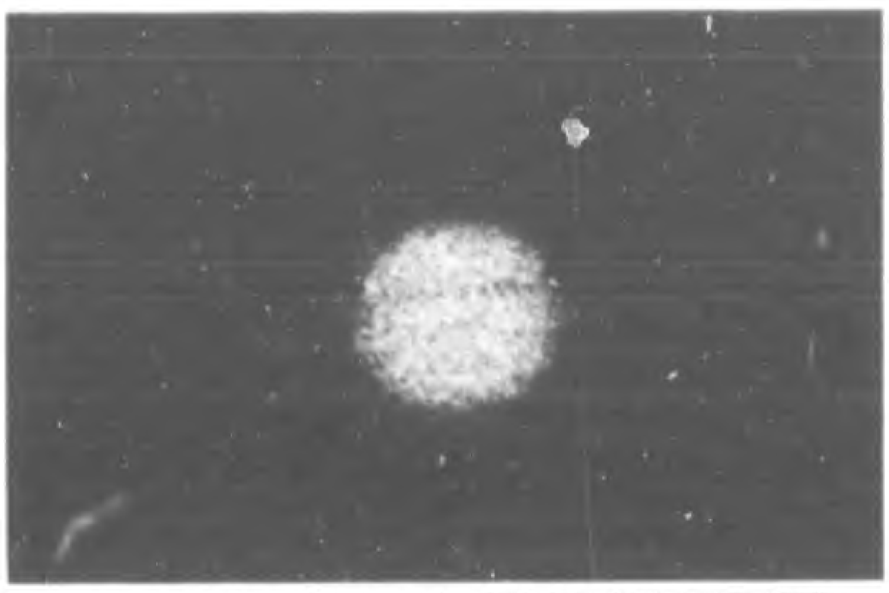
Figure 2. ARL 4-axis, 24-inch satellite tracking telescope.

taneous measurement by imaging and non-imaging techniques. The novel 4-axis design allows hand guiding by a skilled observer to better than 30 arc seconds for most targets.

Nonimaging brightness data are collected by a highly selected photomultiplier utilized in a special logarithmic feedback circuit conceived by Mr. Edmund T. Tyson of AFAL. This highly stable detector system all ws measurements of brightness with 10-percent accuracy over a dynamic range of 100,000. This remarkable sensor is not only stable to better than a few percent over this range, but has also allowed resolution of millisecond-duration flashes from active xenon-beacon satellites of the ANNA type. Data are stored in the form of magnetic analog tapes for future analysis.

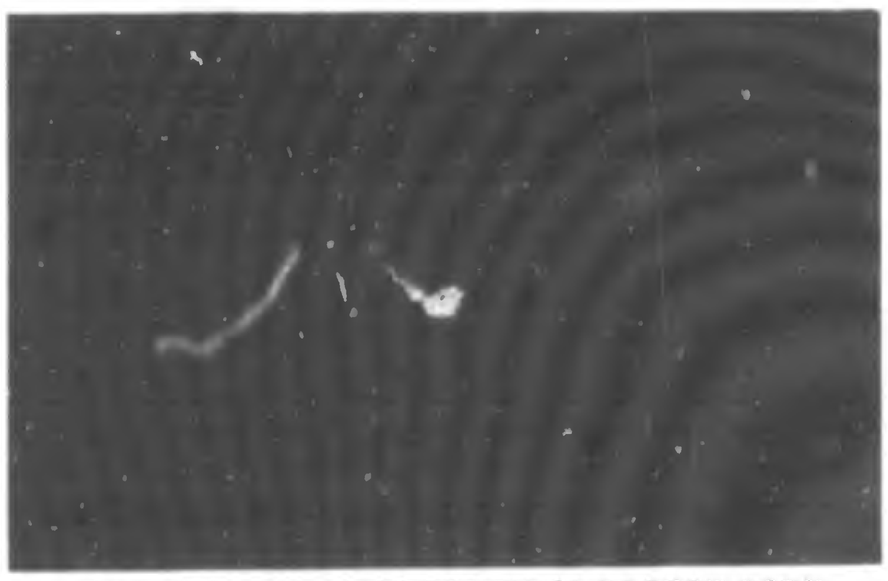
Optical signatures (light curves, in astronomical parlance) have been collected from over 100 different satellites on more than 500 individual transits. Direct photographs resolving some detail have been obtained on only a few vehicles preparatory to installation of a double-beam tailpiece on the ARL telescope for simultaneous imaging and non-imaging detection. Figure 3 shows an example of the resolution obtainable with direct photography.

Analyses of samples of these data have been made for a wide variety of purposes, in addition to their use in verifying basic theoretical predictions. These diverse appli-



COMPARISON OF SATELLITE IMAGES WITH THE PLANET SATURN AT THE SAME SCALE.

SPACE OBJECT 1451 PROTON 8 ROCKET BODY SLANT RANGE 229 KM ON 18 SEPTEMBER 1965



SPACE OBJECT 1627 COSMOS 92 ROCKET BODY 216 KM SLANT RANGE ON 27 OCTOBER 1965

Figure 3. Examples of direct photographic recording of orbiting spacecraft with the OPOS telescope.

cations include: inference of the size and shape of classes of foreign-launched satellites; timing of the xenon-flash discharges on the ANNA B and GEOS A geodetic satellites; measurement of the rotation-rate and orientation changes of various satellites; mapping of the power pattern of the GEOS

xenon lamps to attempt the determination of the verticality of the gravity-gradient stabilization system; and the brightness calibration of several high-altitude satellites being used as test targets for the FSR-2 Electro-Optical Surveillance Sensor under development by the Electronic Systems Division, Air Force Systems Command. Work on surface-finish deterioration and polarization effects is now in progress. Several other offices within the Air Force and the National Aeronautics and Space Administration (NASA) are studying the ARL results. NASA has contracted for construction of a modified copy of the ARL 4-axis instrument for space-materials studies.

general physics

GRAVITATIONAL ENERGY-MOMENTUM LINKAGES

Recently, significant progress has been made in the study of gravitational radiation in the asymptotic regions of space (regions very far from any matter, or from strongly curved regions of space). It was shown that, in the presence of gravitational radiation, the total mass of the system decreases. This intuitive result was derived from a new formalism which uses characteristic or light-like surfaces in place of the usual space-like co-ordinate surfaces. As an unexpected result, it was discovered that the asymptotic symmetry group was not the Lorentz group of special relativity, but a larger and more perplexing group called the Bondi-Metzner-Sachs group.

Motivated by this success, Drs. Louis A. Tamburino and Jeffrey H. Winicour at ARL undertook to study this problem in a larger region of space-time. Extending it to cover finite distances from bounded sources, they contributed toward bridging the gap between the asymptotic and finite versions of the characteristic initial value problem of general relativity. In the finite region, new complications arise because the curvature of space-time generally washes out the symmetry properties one enjoys in the asymptotic region. Since the symmetry properties of a field are closely related to conserved quantities, there is no unique definition of local energy and momentum. This difficulty led to the discovery of new entities called asymptotic symmetry linkages which utilize the asymptotic symmetries for defining physical invariants in the finite region.

The term, linkage, is peculiar and results from the four-dimensional geometry of space-time. In this geometry, a two-dimensional surface of a sphere may be visualized as a loop at some instant of time. (In time, the sphere traces out a cylinder.) The volume enclosed by the two-dimensional surface can be any space-like surface spanning the loop (and lying inside the cylinder). Because there is no unique way of choosing a volume element enclosed by the sphere, it is more meaningful to consider the energy or momentum which "links" the loop in the time direction than to associate a given energy or momentum with a given volume. The two-dimensional loop does determine a unique light-like surface which provides the connection with the asymptotic region. The symmetry displacement vectors can be propagated along the surface light rays into the locale of the loop and, with this data, one can establish the energy and momentum linkages covariantly.

The application of these ideas to global questions will ultimately involve problems of outstanding current importance. Application of the linkages to the structure and dynamics of localized gravitational sources should lead to a better understanding of strong field regions. The association of linkages with asymptotic regions suggests a relationship to the S-matrix problem in general relativity.

GROUP II-VI LASER CRYSTALS

Group II-VI compounds and their solid solutions offer great potential for laser applications in the visible and ultraviolet regions of the spectrum. They offer the potential of operating at any specified wave length between 3200Å (ZnS) and 7772Å (CdTe). Mr. D. C. Reynolds and his associates at the Solid State Physics Research Laboratory, ARL, have grown platelet-type crystals of CdS, CdSe and CdS:Se that have demonstrated laser action at wave lengths between 4900Å (CdS) and 6900Å (CdSe). ZnO single-crystal platelets have also been grown that demonstrated laser action at ~ 3700Å.

The spectral region covered by II-VI lasers is particularly attractive, since it provides high-energy light sources in the visible and ultraviolet. It is also very attractive because it is the region covered by the most sensitive detectors available. Photomultiplier detectors and light amplifiers cover this region of the spectrum. Sensitive detectors are important when one considers applications in the communications field.

Platelet-type crystals are particularly convenient for fabricating laser cavities. The platelets are of the wurtzite structure, and have a preferred cleavage parallel to the "c" axis. Cavities as shown in Figure 1 are readily prepared by cleaving with a razor blade or similar object. The broad face of the cavity is bombarded with electrons, and the laser radiation is emitted from the cleaved faces. A magnified image of an actual cleaved-cavity edge is shown in Figure 2.

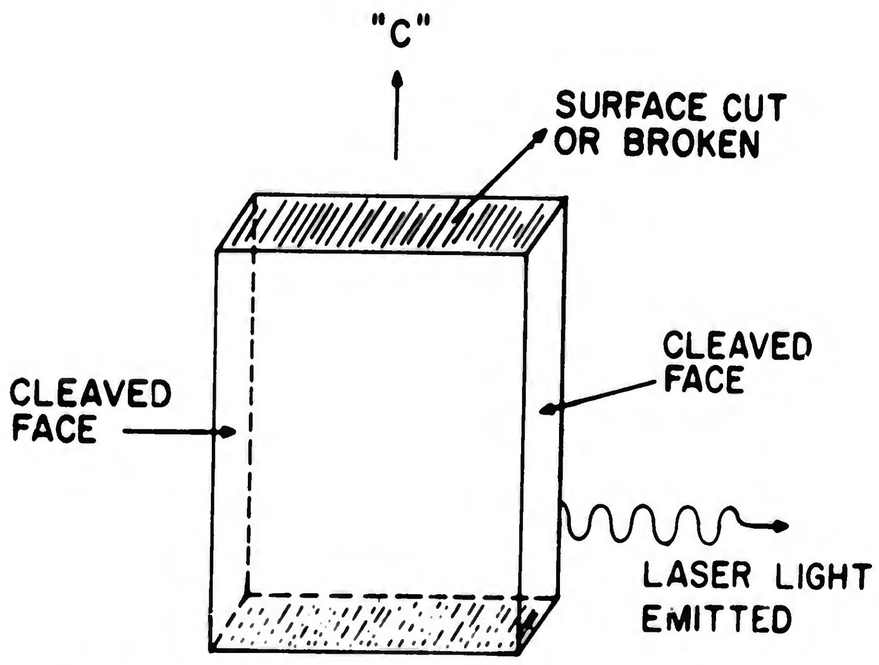


Figure 1. Platelet crystal with laser cavities cleaved parallel to c-axis.

Figure 2. Magnified image of cleaved cavity edge.

RECOVERY OF HIGH-PRESSURE PHASE OF CdS

Drickamer and coworkers first reported a crystal-structure transformation in CdS in the pressure range 20-30 kilobars. Troitskaya and Kalbalkina and other authors have investigated the structure of the high-pressure phase of CdS using X-ray techniques. They report that the original wurtzite (hexagonal) structure transforms to a NaCl structure in the pressure range 20-35 kilobars. The NaCl structure transforms to the zinc-blende (cubic) structure, with a small admixture of wurtzite structure, when the pressure is released.

Dr. B. A. Kulp and Capt K. A. Gale, at the Solid State Physics Research Laboratory, ARL, have succeeded in recovering the NaCl structure at room pressure at a temperature of 77°K. The starting material was single-crystal CdS. The recovered NaCl structure contains relatively large areas of single crystal, along with areas of relatively unstrained powder. The recovered material is black in color with a shiny metallic-like luster. After annealing the recovered sample to room temperature, the crystal structure transforms to the zinc-blende-wurtzite structures, which are red in color.

The crystals used in this work were grown and prepared in the Solid State Physics Research Laboratory, and were Li-doped to give them added strength. The starting samples varied in thickness from 2.5 to 36 mils, with the c-axis perpendicular to the flat of the crystal. The high-pressure bomb used in the work was modeled after Drickamer's high-pressure optical bomb. The sample chamber was 3/16" x 1/8", and the working fluid was NaCl.

The crystals were loaded into the bomb and then pressurized to 37 kilobars. By immersing it in liquid nitrogen, the bomb was cooled to 77°K while under pressure. The pressure was then released, the bomb was disassembled under liquid nitrogen, and the sample recovered from the resulting pellet. The recovered samples could be stored in liquid nitrogen for several days, with no apparent ill effects.

The absorption edge of the NaCl-structure CdS has been measured using a Cary photospectrometer. The resulting edge is shown in Figure 1. The curve on the left is the absorption edge of a pure CdS platelet with the wurtzite structure. The curve on the right is the absorption edge of the recovered NaCl-structure CdS. For these measurements, the recovered sample was left on one half of the salt pellet. The scattering at the top edge of the absorption edge is due to the crystal-salt interface. Using the previously published value of 4,850A for the CdS wurtzite absorption edge at 77°K, the absorption edge of the CdS-NaCl structure is at 2.04±.02ev.

There is a 30-per-cent volume change associated with the NaCl-to-zinc-blende transformation. The zinc-blende structure, therefore, is a highly strained powder. The transformation temperature of the NaCl to zinc-blende structure was measured, using optical density measurements. The optical transmission of the zinc-blende structure is much lower than that of the NaCl structure since the zinc-blende form is a powder. A 36-mil sample transformed at 150°K, and 4.0-mil and 2.5-mil samples transformed at 110°K and 80°K, respectively.

Preliminary Laue back-reflection X-ray studies show that, when the starting crystal is 36 mils thick, the recovered sample is a powder. Starting with a crystal thickness of 4.0 to 10.0 mils yields a polycrystalline sample; starting with a crystal thickness of 4.0 mils or less yields a sample with areas of single-crystal NaCl structure. These results are consistent with the annealing-temperature data discussed above. One would expect that the recovered samples containing areas of single-crystal material would be less strained than the recovered samples

which are powdered, and the unstrained crystals would anneal at a lower temperature.

Considering the annealing-temperature data, the results of the X-ray work, and the sharpness of the absorption edge, we conclude that we have recovered the high-pressure phase of single-crystal CdS in a relatively unstrained, single-crystal form.

This work also has value in EPR studies by giving us the capability to study various paramagnetic impurities in the same compound in different crystalline fields. Further work is being done with CdS in the NaCl phase.

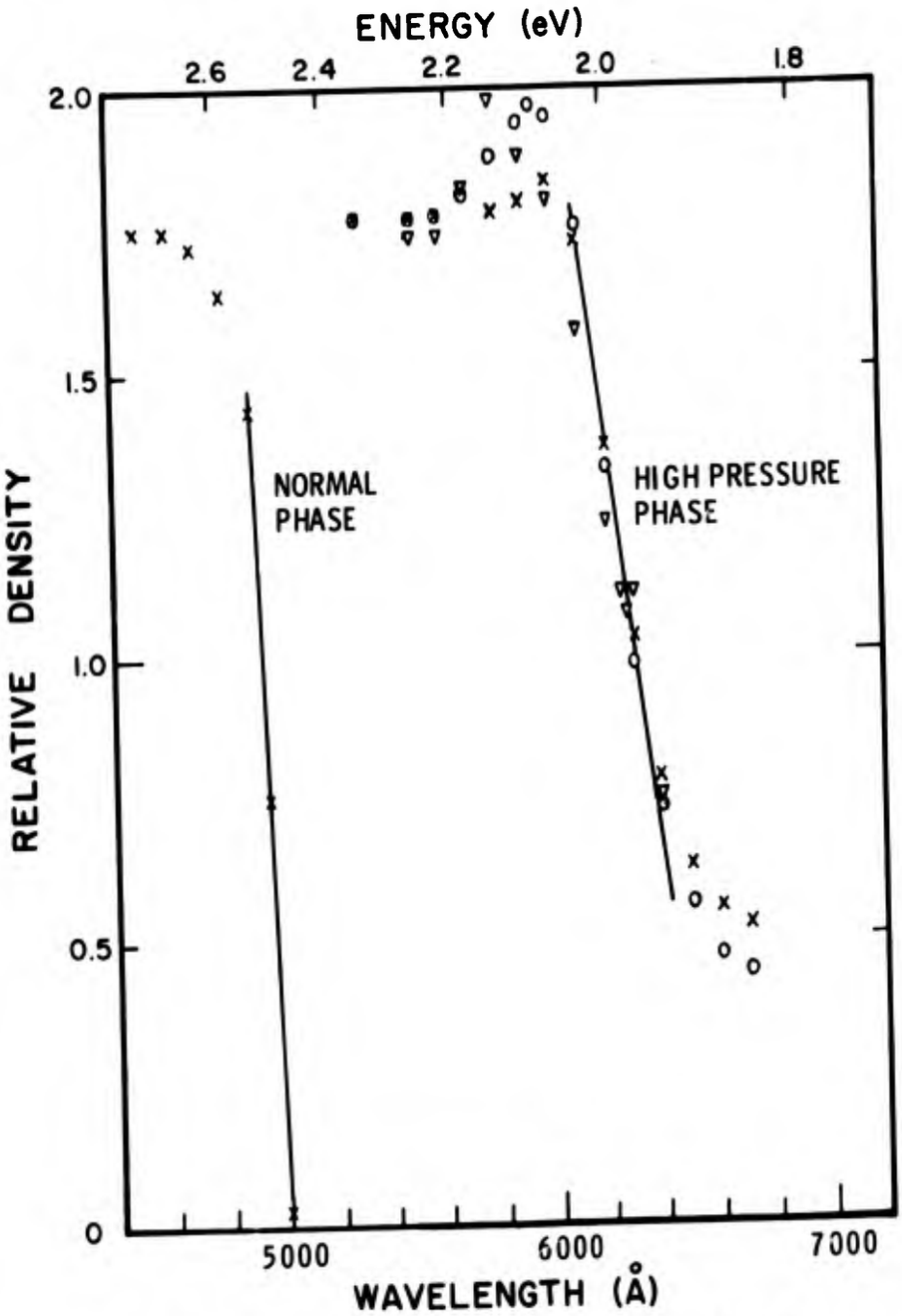


Figure 1. Absorption edge of CdS with NaCl structure (right) and absorption edge of CdS with wurtzite structure (left).

LARGE SINGLE CRYSTALS OF SELENIUM

The science of single-crystal preparation is one of the mainstays of our materials-research effort. Our present-day electronics and space technology, with its spectrum of semiconductor products, depends ultimately upon the preparation of single-crystal semiconducting material. The development of single-crystal preparation from an art into a science has been a long and difficult process, and the path of crystal growth has been beset with a wide variety of difficulties. Many of the problems are common to all crystals--dislocations, lineage boundaries, impurity fluctuations, and the like.

AFOSR has recently cosponsored a research program with Westinghouse Research Laboratories, part of which included a study of the crystallization of selenium, an elemental semiconductor which fails to grow at adequate rates under conventional laboratory conditions. The purpose of the research was to develop a means of growing really large selenium crystals at reasonable rates, and to make these available for study, for selenium is, at present, one of the least-known elemental semiconductors.

At atmospheric pressures, it is, experimentally, not too difficult to make the transition from a polycrystalline ingot to single-crystal growth. The furnace is adjusted to have gentle temperature gradients, and the ingot mold is made with a tapered end so that a single grain may predominate over the many that are initiated there. The optimum rate of normal freeze is then determined. The final important condition in the growth of the resulting single grain is that the interface remain more or less planar, and that supercooling be avoided in the liquid. If supercooling does occur, stray grains nucleate ahead of the interface, either in the body of the melt, or in the walls of the container.

To grow selenium, these same criteria had to be met, not at one, but at 5,000 atmospheres pressure. Fig. 1 shows the apparatus developed by Dr. D. E. Harrison and W. A. Tiller (1, 2, and 3) for the growth of large crystals. Selenium was contained in an open quartz vial within a Stellite pressure bomb. Prior to the work at Westinghouse Research Laboratories, the largest selenium crystals

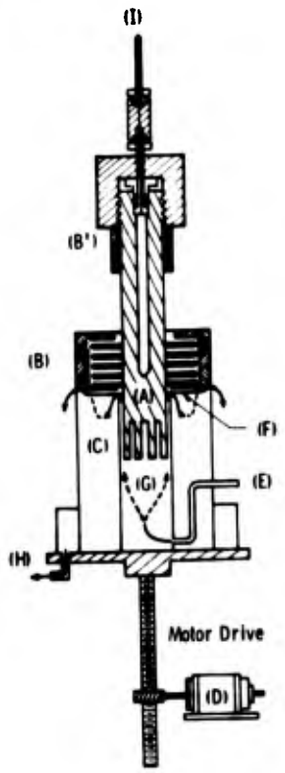


Figure 1. Apparatus for melt-growth of selenium single crystals under high pressure.

The Stellite bomb (A), which contains selenium in a quartz tube, is subjected to 5,000 atmospheres argon pressure through inlet (I). Heaters B and B' raise the selenium temperature above its melting point; then a controlled temperature gradient is passed through the molten sample, causing it to solidify. The combination of fins on (A), heater (B) and water bath (C, E, F, G and H) produces a thermal gradient of ~45° C/cm. The gradient is moved by drive motor (D) lifting (B, C, G) upward around fixed bomb (A). Under these conditions, crystals of selenium about 1 centimeter in diameter and 10 centimeters long can be grown at 0.15 to 0.4 cm/hr.

that had been grown were 1.5 x .7 x .6 cm over all, in the form of imperfect hoppers. The culminating step by the Westinghouse researchers was the production of single crystals of selenium, 1 cm in diameter and 10 cm long.

Fig. 2 shows large ingots of single-crystal selenium. For the top ingot, initial growth was from the tapered end, and was polycrystalline; but single-crystal growth prevailed over the bulk of the ingot. The growth direction was 10 to 40 degrees off the rhombohedral "c" axis. There seems to be little question but that the success of this process can be ascribed to the very careful control of the thermal environment.

Crystal growth from the melt at high pressures is still in the very early stages of development. It is tempting, however, to speculate on the possibilities of obtaining crystals of other materials with polymeric melts. Polyethylene may be a possible candidate. Of course, the chain length in polyethylene and related compounds is considerably greater than that of selenium, and the problem of growing large, single, organic polymer crystals is thus much more formidable. But it does appear that the use of elevated pressures is a step in the right direction. Polymer crystals would be widely welcomed, for they would make possible the determination of accurate bulk properties, quantities which at present are not known with any precision.

The achievement of the Westinghouse researchers in the field of crystal growth and of solid-liquid kinetics is a signal demonstration of progress in 15 years of growing semiconductor crystals by well-established techniques. Solid-state scientists concerned with basic structure-sensitive properties of materials now have pure single crystals of ample size on which they can perform reproducible experiments and controlled measurements of the electronic structure and the semiconducting properties of selenium. (4)

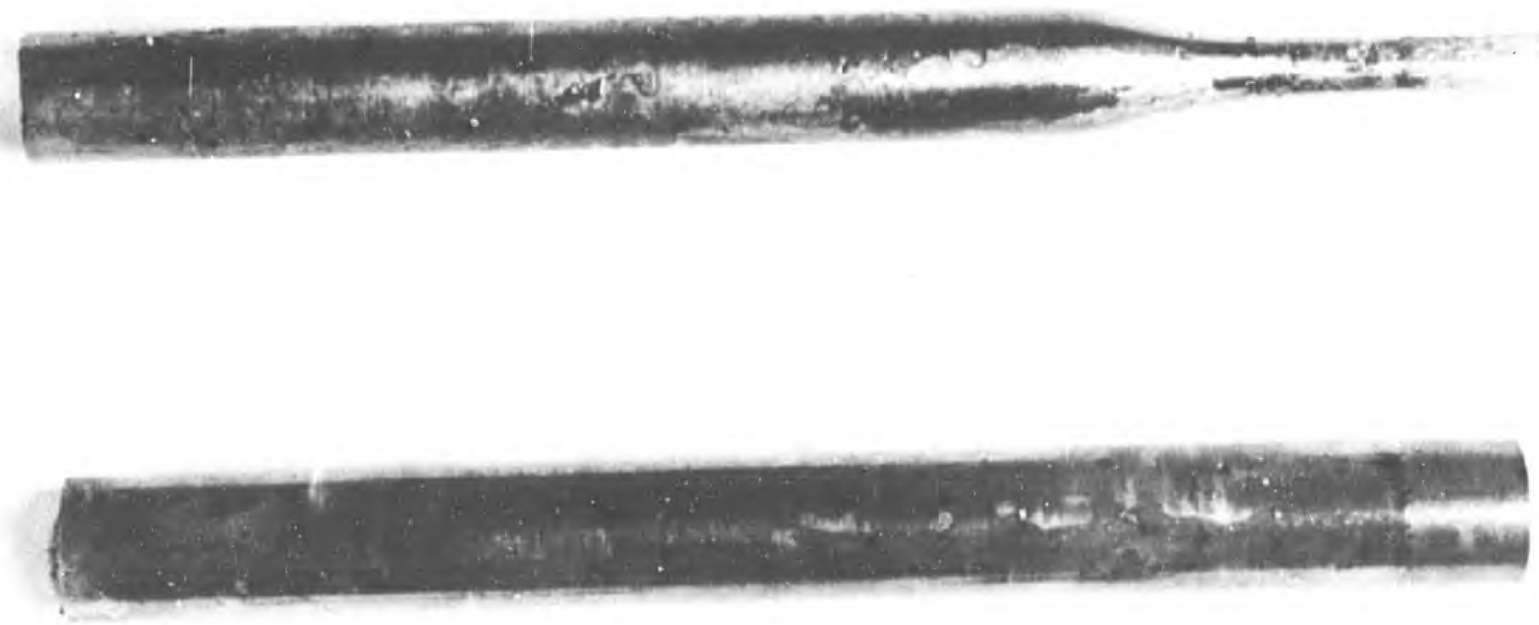


Figure 2. Large crystals of selenium. The two top crystals have been grown parallel to the "c" axis, the topmost crystal from a subdiameter seed, and the middle crystal from a full-diameter seed. Note the whiskers (needle-like crystals) at the left end of the middle crystal (top end during growth). A section which has been cut from a crystal and cleaved parallel to the "c" axis appears with the inch-scale marker.

FERRITE-PRECIPITATED MAGNESIUM OXIDE —A NEW MATERIAL

Ferrite-precipitated MgO consists of tiny precipitated crystals of magnesio-ferrite, nominal composition $MgFe_2O_4$, dispersed in a matrix of MgO. This material has potential application, for two reasons. The precipitated crystals improve the mechanical properties of MgO, a ceramic material, and since magnesioferrite is a ferrimagnetic oxide, there are possible electronic applications. The material was developed by Drs. G. W. Groves and M. E. Fine at Northwestern University in AFOSR-sponsored research. (1) Dr. Fine and his group are continuing their research on this material and on other precipitated ceramics as well.

In heat treating oxide ceramics, in contrast to metals, one must control the oxygen pressure as well as the temperature. Iron exists in two valence states, divalent iron, Fe^{++}, as in FeO (wüstite), and trivalent iron, Fe^{+++}, as in Fe_2O_3 (hematite). With Fe^{++} present, MgO and FeO are completely soluble in each other like water and alcohol. In air at 1,400°C where about 70% of the iron in Mg-Fe-O is Fe^{+++}, MgO will dissolve Fe only up to 20 cation %, and the solubility decreases drastically as the temperture is lowered. By rapidly cooling to room temperature from 1,400°C, the Fe is maintained in solution. This solution is supersaturated and, if the (Mg,Fe)O is heated to some temperature such as 800°C, the Fe^{+++} precipitates as magnesioferrite ($MgFe_2O_4$) in the shape of octahedra.

One of the ways in which metals are strengthened is by putting a second metal into solution in the first meral. Another way is by forming precipitates. Both occur in Mg-Fe-O, as shown in Fig. 1. The strength of a pure MgO single crystal is 11,000 lbs./in² (8 kg/mm²). Adding 1.35 cation % Fe at 1,400°C in air and maintaining it in solution by quenching (air cooling) to room temperature strengthens single crystals to 21

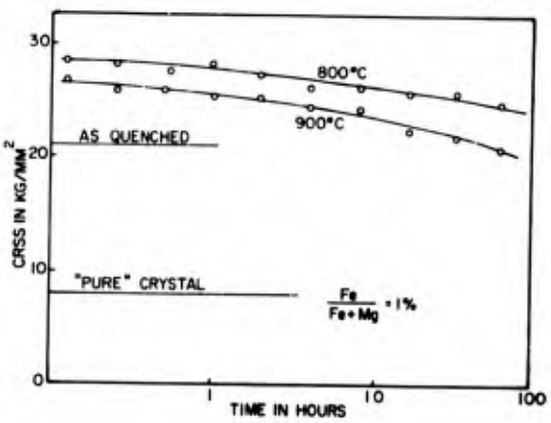


Figure 1. Effect of precipitation anneal on critical resolved shear stress of MgO alloyed with 1.35% Fe/(Fe + Mg) in air at 1,400°C. The samples were air-cooled to room temperature before aging.

kg/mm². The magnesioferrite precipitates formed by aging a few minutes at 800°C strengthen MgO to 29 kg/mm², or 40,000 lbs./in². The yield strength of MgO single crystals has thus been increased by a factor of about 4 by adding only 1.35 cation % Fe. Further strengthening could no doubt be achieved by increasing the Fe^{+++} content.

A study of the static magnetic properties of the magnesioferrite precipitates has just been completed by Dr. G. P. Wirtz. (2) The magnetic properties offer an excellent way for studying the precipitation process in this system.

Curves of magnetization versus applied field are presented in Fig. 2, for 4 hrs. of aging at 800°C. Data are shown for three temperatures: ambient (25°C), liquid nitrogen (-196°C), and liquid helium (-269°C). The curves at 25°C and -196°C do not show the usual hysteresis seen in magnetic materials. This is because of the small particle size for this treatment; the particles are super-

paramagnetic. The alignment of the particles by the applied magnetic field is opposed by thermal disordering. Note that the saturation magnetization increases on cooling. The particles precipitated at 800°C are not ferrimagnetic above 220°C, their Curie temperature. The Curie temperature here depends on the aging temperature; it is 250°C for 700°C aging.

The saturation magnetization, determined from curves like those in Fig. 2, reaches 80% of its maximum value within 15 minutes of aging at 800°C, and remains virtually constant after 1 hour of aging. Final saturation magnetization values of 6.3 and 3.6 emu./cm³ at -196°C and 25°C, respectively, were obtained in a sample of 0.7 cation % Fe^{+++}.

The initial susceptibility of the sample increases linearly with the number of particles, and quadratically with the size. It decreases as the measuring temperature is increased. At -196°C, initial susceptibilities as high as 0.08 emu./cm³-oersteds were obtained by aging a sample of 0.7% Fe^{+++} for 145 hours at 800°C. Increasing the initial susceptibility by more than an order of magnitude seems feasible by simply increasing the initial concentration of Fe^{+++}.

Thus by the precipitation technique, one can obtain extremely copious, fine ferrimagnetic particles distributed in an insulating matrix. This is an interesting and a new type of magnetic material. One possible application is as the memory of a computer, since the precipitated particles are all single crystals, oriented in the same direction, and distributed at very high densities but not in contact with each other. Moreover, the size and number density of particles can be carefully controlled. Another possible application is for radar absorption. A body coated with

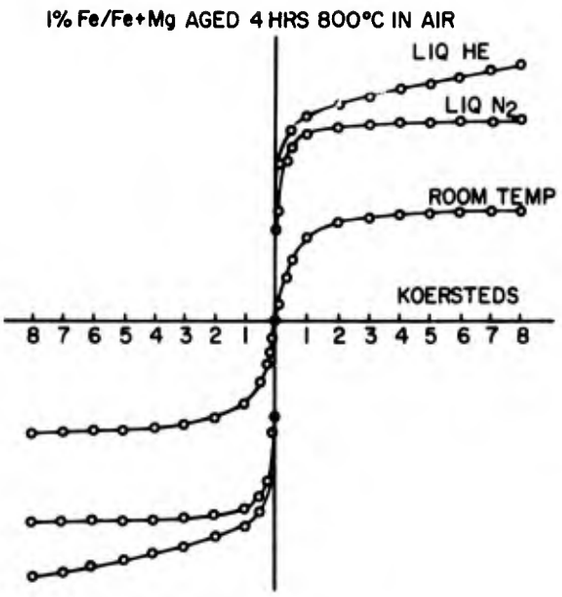


Figure 2. Magnetization curves for 1% Fe/(Fe + Mg) aged 4 hours at 800°C (after air cooling from 1,400°C).

the proper thickness of material is made less visible to radar. In addition, because this new material is made up of magnetic particles embedded in a dielectric medium, and each particle is small enough to encompass but a single magnetic domain--and if hysteresis effects could be minimized--these characteristics could provide a superparamagnetic material which might be alternately polarized with magnetic spins flipped in one direction or another without involving domain wall movement. In these circumstances, it might be possible to make small, low-frequency transportable antennas which could be reasonably efficient, handle sizeable power, and contribute greatly to the survivability of defense communications systems.

general physics

GYROSCOPE TO TEST GENERAL RELATIVITY

Although Einstein's relativistic theory of gravitation, the general theory of relativity, has a clear conceptual superiority over Newtonian gravitation, it has proven extremely difficult to establish this superiority observationally. In order to verify the theory, phenomena must be observed in moderate gravitational fields at high speeds (in terms of the velocity of light), or in strong gravitational fields at moderate speeds. Unfortunately, the available fields such as those at the surfaces of the sun and earth are ex-

tremely weak. However, work at Stanford University, supported by the Nuclear Physics Division of AFOSR, has led to the development of a new important test of the general theory of relativity which is now rapidly progressing to the point of being tried in practice.

Some years ago Professor L. I. Schiff of Stanford University showed that a perfect gyroscope, subject to no external torques, and orbiting the earth in a satellite, will experience an anomalous precession with respect to the fixed stars as it travels around the earth. For a typical orbit, the predicted shift of the direction of the axis of rotation of such a gyroscope is only 7 seconds of arc per year. According to the general theory of relativity, the precession arises as a result of the earth's mass distorting space-time in its neighborhood. A second, much smaller "anomalous" precession (of the order of 0.05 seconds of arc per year) is due to the earth's "dragging the metric with it" as it rotates.

Professor William Fairbank of Stanford University, and his colleagues, Drs. W. Hamilton and F. Everitt, have been working for some time toward a gyroscope that will be able to detect these very small precession rates. The gyroscope will be a quartz sphere of high accuracy (to avoid torques due to the gradient of the gravitational field), and will be coated with a superconductor. Since a spinning superconductor develops a magnetic moment (called the London moment) along its axis of spin, the direction of the gyroscope's axis can be determined magnetically. To achieve the required accuracy, a superconducting magnetometer with a potential sensitivity of 10^{-11} Gauss was developed. The quartz sphere, once it is in orbit, will move completely free in a vacuum, surrounded by

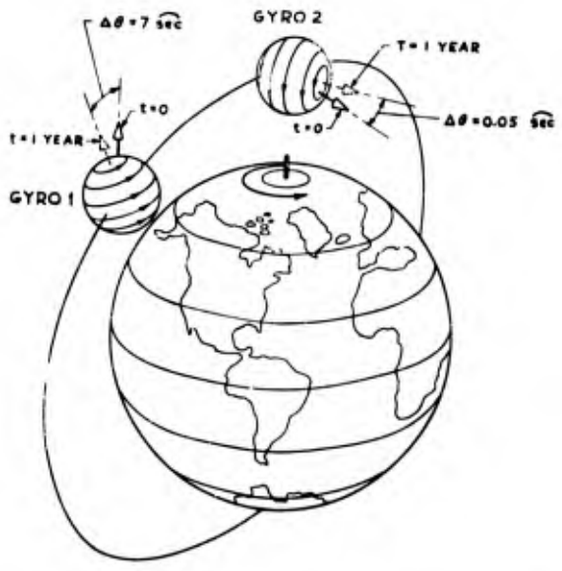


Figure 1. Relativistic precessions of gyroscopes in 500-mile polar orbit.

a quartz shell also coated with a superconductor. The function of this outer superconducting coating is to exclude all external magnetic fields, since these would interact with the London moment, causing the gyroscope to precess. The construction of these perfect magnetic shields, which provide the experimenter with a relatively large volume in which the magnetic field is absolutely zero, is a significant achievement, and underscores the increasing practical usefulness of superconductors. (The Stanford team is constructing a zero-magnetic-field facility, which will be able to provide such magnetically shielded regions to users all over the world.)

In order to provide a double check on each of the two independent precession rates, four gyroscopes will probably be launched into a polar orbit within the next few years.

SOURCE-DETECTOR STUDIES IN THE SUBMILLIMETER REGION

general physics

Professor P. D. Coleman of the University of Illinois reports the successful completion of a large, vacuum, fully instrumented monochrometer for studies of the absorption and emission of radiation in the submillimeter-far-infrared region of the spectrum. This employs 16" x 16" main gratings, plus 2 accompanying filter gratings enclosed in a removable, vacuum-tight housing. Auxiliary equipment includes cryogenic detectors,

lock-in amplifiers and recorders. The spectrometer has been calibrated with numerous measurements utilizing CH_3NH_2, NO and H_2S molecules of the type that will have important applications to far-infrared gas lasers. It has been employed to measure the wave length of lines from the H_2O laser.

Professor Coleman also reports that lasing has been achieved in n-type GaAs bombarded with 30-kv electron beam at temperatures of 4.2°, 77° and 195° Kelvin. This was the first report of lasing at 77° and 195°K for this semiconductor material.

general physics

OPTICAL NONLINEARITIES

Optical nonlinearities in solids are usually extremely small. Hence, it was not until the advent of the laser that investigations of nonlinear optics became important. The reason for this was that conventional light sources were not sufficiently intense or coherent to make the effects of nonlinearities noticeable. In 1961, the high-intensity light from a ruby laser was first used to demonstrate the generation of optical second harmonics in crystalline quartz. (1) Thus, the interaction of light with itself through a nonlinear effect in a material medium was observed for the first time. Since then the field of nonlinear optics has grown enormously.

At Stanford University, in the past several years, Professor A. E. Siegman and his colleagues, supported by AFOSR, have studied the theoretical and experimental aspects of optical second-harmonic generation by an actual gas-laser beam. (2, 3, 4) This arrangement has permitted the observations to be carried out on a continuous basis, although the intensity of light was not as high as that of the Q-switched ruby laser employed earlier by others. Since the CW laser used was inherently low in power, a special arrangement was employed continuously to generate measurable amounts of second-harmonic power. In this case, the specimen birefringent crystal was so oriented that the index of refraction for the "ordinary ray" for the laser beam matched the index of refraction of the "extraordinary ray" for the harmonically generated beam. Thus, the velocity of the original laser beam and that of the harmonic beam were the same as the two beams travelled through the crystal. Furthermore, the laser beam was focused to enhance the

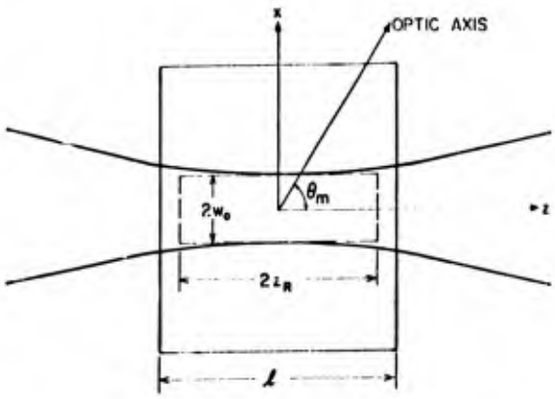


Figure 1. Schematic diagram of the laser beam focused in the center of the crystal. The cylindrical approximation for the focused beam is shown by the dashed figure.

effect. (See Fig. 1) The basic theory of second-harmonic generation in index-matching crystals had previously been developed for the idealized case of a simple plane-wave laser beam. (5, 6, 7) However, one must be very careful in applying the results of this theory to experiment because they are valid only in certain limiting cases. This is true because an actual laser beam is finite in extent; thus, it must be represented as the sum of many plane waves propagating in a distribution of directions. This means, then, that the details of second-harmonic generation for an actual laser beam can be very different from those predicted by simple plane-wave theory. In calculating the results which are expected from an experimental arrangement, one must take this difference into account. This has been done in this research.

The general case of second-harmonic gen-

eration by an index-matching crystal placed anywhere along a laser beam has been considered at Stanford University. Two special aspects of the general problem were experimentally investigated. These are: (1) second-harmonic generation in the focus of the beam; (2) the dependence of the second harmonic power upon rotation of the crystal away from the index-matching direction. Attention was directed to the general problem of actual laser beam and to the two specific cases for these reasons: (1) they correspond to the cases of most experimental interest; focusing is a very important case since, through the use of a focused beam, one can extract much greater amounts of second harmonic power; (2) an exact theory for an actual laser beam is essential if comparison with the results of precise measurements is to be fruitful.

The method used to analyze the general problem was to apply the basic plane-wave theory to each of the many plane waves which comprise the real laser beam. The resulting formula indicated that the power in the second harmonic depended upon the crystal length, the minimum spot size at the focus, the angle of double refraction in the crystal, the angle between the direction of the laser beam and the direction in which the indices are matched, and the distance of the crystal from the focal plane. The experimental results were found to be in excellent agreement with the theoretical expression. The experimental arrangement is shown in Fig. 2.

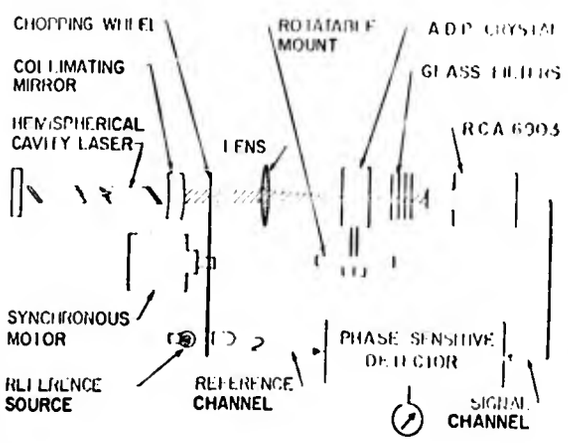


Figure 2. Schematic representation of experimental arrangement.

Second-harmonic generation in the focus of a laser beam depends on the ratios of three lengths: the length of the crystal in which the second harmonics are being generated; a length characteristic of the focal region of the beam; and a length characteristic of the beam focal-spot radius and the crystal double-refraction angle. It was then shown that there is an upper limit to the power which can be extracted from a given crystal. Corresponding to this maximum power there is an optimum degree of focusing, which is determined only by the crystal length and is independent of crystal double refraction. This means that, for optimum focusing, the energy must be distributed throughout the crystal in the best possible fashion.

This prediction was experimentally verified using 3 crystal lengths of ammonium dihydrogen phosphate (ADP), and also in calcite. For instance, a focused beam in a crystal of ADP 1 cm long yields about 400 times more second-harmonic power than does a collimated laser beam.

The dependence of the second-harmonic power on rotation of the crystal from the index-matching direction was also investigated on the basis of the theory mentioned above, namely, considering the laser beam to be made up of a number of plane waves proceeding in a distribution of directions. The results of the calculation were applied in experiments designed to make accurate measurements of the nonlinearities in crystals of ADP. Observations corroborated this theory. The results were significantly different from those which would have been predicted from a simple plane-wave theory. The measurements of the relevant nonlinearity coefficient are considered to be among the best now available, and permit crystals such as ADP or KDP to be used as secondary standards against which to compare nonlinearities in other crystals. Thus, these results have substantially improved the accuracy with which measurements can be made in the rather difficult area of optics.

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NUCLEAR ISOBARIC ANALOG STATES

One aspect of the nuclear-research program involves accelerating protons to very high velocities, and shooting them at a target nucleus. For example, in one project being conducted in the nuclear-structure laboratory by Dr. D. D. Watson of ARL, a target of S^{34} is bombarded by protons. At certain discrete proton energies, the probability that the S^{34} nucleus will capture a proton and be transmuted to Cl^{35} is quite high, relative to other proton energies. This sudden increase in the capture cross section is called a resonance. The Cl^{35} nuclei thus formed are in a highly excited state, and de-excite to the Cl^{35} ground state by emitting gamma rays. A study of the gamma radiations resulting from the proton-capture reaction provides a powerful means of investigating the excited states of such nuclei. We shall discuss one of these resonances below.

A resonance which attracts immediate notice occurs in the S^{34} + p capture cross section at a proton energy of 1.214 million electron volts. It is about 10 times stronger than any one of several dozen other nearby resonances, and must thus somehow be of a very special nature. Indeed, it also has an unusually simple mode of gamma-ray de-excitation in that it decays from the resonance level to the ground state by a cascade through only one of the many other nuclear excited states, and does so with a gamma-ray transition strength of about 10 times the normal strength. Measurements of the intensity angular distributions and linear polarizations of the gamma rays have fixed the spins and parities of both the two involved excited states as $7/2^-$.

This behavior can be understood largely on the basis of a very simple model. Imagine that some of the protons which were shot at the S^{34} target nuclei simply go into a quantum orbit around those nuclei. The system of orbital proton and S^{34} is a highly excited state of Cl^{35}. If the proton carries in three units of orbital angular momentum (along with its intrinsic spin), the proper spin and parity, $7/2^-$, will result. This extreme single-particle model, in fact, gives rise to two orbital $7/2^-$ states which are the same except for energy and isobaric spin. These two $7/2^-$ states can be identified with the upper and lower energy $7/2^-$ states observed in Cl^{35}. Further comparisons can be made between the model and the experimental information. Very good agreement is obtained for the lifetime of such an orbital state, and also for the calculated gamma-ray transition strength between the two $7/2^-$ orbital states. Finally, suppose that the orbiting proton were, instead, an orbiting neutron. If the nuclear force is charge-independent and much stronger than the coulomb force, such a neutron orbital state should exist. The nucleus in this case would be S^{35} instead of Cl^{35}, and the energy of this state in S^{35} would be displaced from that in Cl^{35} by the proton coulomb energy. This neutron orbital state turns out to correspond to the first excited state of S^{35}, which does indeed have all the properties to make it the analog of the proton orbital state in Cl^{35}. Such a pair of states in nuclei of the same atomic number, but different charge, are called isobaric analogs. The similarity and the energy, spin, parity, formation and transition probabilities of these states can thus be explained on the basis of a very simple assumption about their nature.

The above example is no longer isolated. Four other single-particle, isobaric analog states have now been identified in the work on Cl^{35}. Several other similar states have been identified by Dr. G. I. Harris of the nuclear-structure laboratory in the P^{30} and P^{31} nuclei. Still other similar cases discovered in other laboratories are now being reported in the literature. The nature of these states was also the subject of considerable discussion at an international symposium on the structure of low-medium mass nuclei held at ARL in April 1966.

nuclear physics

PARTICLE-DETECTION EXPERIMENT ABOARD THE MARINER IV

The Mariner IV spacecraft was launched in November 1964, and passed within 9,850 kilometers of the planet Mars in July 1965. One of the instruments carried aboard this spacecraft was a solid-state charged-particle telescope designed to detect electrons of energy greater than 40 KeV, and protons of energy greater than 1 MeV. This instrument provided information concerning the particle spectra and particle fluxes throughout the 228-day trip to Mars.

In addition to providing data about the cosmic-ray particles in the solar system, the cosmic-ray telescope was used to determine the magnetic field of Mars. If Mars has a dipole magnetic field similar to the earth's magnetic field, then charged particles should be trapped in this field. Also, solar winds should produce a magnetic bow shock front when impinging upon this field. Thus, if Mariner IV passed through the bow shock front, the shock transition region, or the magnetospheric boundary of Mars, then an increase in the charged-particle flux should have been detected by the charged-particle telescope. However, no detectable increase in activity was observed during the approach to Mars. Hence, an upper limit can be calculated for the magnetic moment of Mars. This moment has been determined to be less than one tenth of a percent of that of the earth's magnetic field.

This experiment was conducted by Professor J. A. Simpson, an AFOSR grantee, and his group at the Enrico Fermi Institute for Nuclear Studies, University of Chicago. This group designed and fabricated the charged-particle telescope carried on the Mariner IV, and has analyzed the data obtained from it. The results of its search for the magnetic moment of Mars were published in Science. (1)

nuclear physics

HIGH-ENERGY X RAYS FROM THE CRAB NEBULA

A supernova is a star which explodes catastrophically, with the sudden release of a large fraction of its energy. Initially, it is brighter than all but the largest of the galaxies; however, shortly after its occurrence, its luminosity decreases exponentially. Theories differ as to the cause of the supernovae, and as to whether the source of the energy released is based upon gravitational or nuclear forces. Only by experimental verification can it be determined which of the theories is more nearly correct.

With this in mind, Professor R. Haymes of Rice University, supported by AFOSR, has conducted an experiment to yield a better understanding of supernovae. He and his associates have designed and built a gamma-ray telescope of good angular resolution, and have connected it to a multichannel pulse height analyzer to achieve energy resolution. The instrument was designed to detect gamma rays in the energy range from 23 KeV to 455 KeV. The telescope, which, with its associated equipment, weighs about 800 pounds, must be carried aloft by plastic balloon to a high altitude in order to detect the low-energy gamma rays before they are absorbed by the atmosphere. On October 19, 1965, Dr. Haymes launched the telescope for the first time to observe the electromagnetic spectrum of the Crab Nebula. (The Crab Nebula is a remnant of a supernova that occurred in the year 1054 A.D., and is still visible today as an irregularly expanding nebula.)

The results of the first flight showed that the Crab Nebula emits a relatively large flux of X rays up to an energy of 80 KeV,

and that the X-ray spectrum can best be approximated by a single exponential over the entire energy range. This implies that the X rays emitted by the Crab are caused by bremsstrahlung from a hot gas. This finding is contrary to the theory that the Crab emits X rays via the synchrotron mechanism, since the synchrotron mechanism would produce a power-law energy spectrum. Another implication to be derived is that the temperature of the hot gases in the Crab Nebula must range as high as 100 million degrees Kelvin. This high temperature could conceivably be achieved in the regions of the Crab where there are shock fronts in the plasma streams of the nebula. This phenomenon is analogous to the shock fronts produced by the solar wind impinging on the magnetosphere of the earth where temperatures of 10 million degrees occur.

Further flights, at a somewhat higher altitude, will be undertaken to study the gamma-ray spectrum from the Crab in more detail, as well as to observe other interesting stellar objects which emit X rays and perhaps nuclear gamma rays. These experiments should be of great benefit to theorists in arriving at a suitable model for supernovae.

nuclear physics

LONG-RANGE ELECTROMAGNETIC FORCES ON NEUTRAL SYSTEMS

A traditional problem in the physical sciences concerns the nature of the forces acting between two neutral systems for which the gravitational attraction is too weak to be of direct interest. Such forces act between two neutral molecules, and these intermolecular forces determine, among other things, the surface tension and viscosity of liquids and their solubility in other liquids. Intermolecular forces of this type, called van der Waals forces, are long-range forces; that is, they fall off at large distances as an inverse power of the distance r between the bodies, rather than exponentially.

The first quantitative theory of van der Waals forces was advanced by the German physicist, Fritz London, in 1930. In this theory, a particular dynamical model is assumed, and the intermolecular forces arise from the electrostatic interaction between two dipoles. The energy of the interaction turns out to be proportional to r^{-6}, and the force to r^{-7}. London's approach is not valid at large separations due to the neglect of retardation effects in the interaction between the two neutral systems. The retardation effects were first considered by the Dutch physicists, H.G.B. Casimir and D. Polder, in 1948. Casimir and Polder found that, at relatively large distances, the interaction energy and the force are proportional to r^{-7} and r^{-8}, respectively, in contradiction to the London expressions.

Recently, in a paper published in the Physical Review, Professors J. Sucher of the University of Maryland and G. Feinberg of Columbia University described their more general quantum-field-theory calculations of the forces acting between pairs of particles, at least one of which is neutral and spinless (i.e., has no angular momentum). This work, supported in part by the Nuclear Physics Division of AFOSR, was pursued to establish whether or not such long-range forces are presently observable in particle physics. It turned out that, for the particle physics problem they considered -- the long-range force between K-mesons -- the long-range force effects were not experimentally detectable. Another interesting result of their work was the proof that the result of Casimir and Polder concerning van der Waals forces is quite general, being independent of the detailed dynamical models for the individual interacting systems. However, due to the binding of atoms by electromagnetic interactions, there is an exponential term in the expression for the interaction energy, which may dominate the interaction potential for many atomic radii before the r^{-7} terms be-

come of importance.

Since the nature of forces between atoms determines the properties of macroscopic matter, the improved understanding of these forces gained from the work of Feinberg and Sucher is clearly of importance in connection with attempts to comprehend and predict such properties.

chemistry

PERCHLOROCARBONS OPEN NEW CHEMICAL HORIZONS

Substances constituted exclusively of chlorine and carbon are called perchlorocarbons. To every hydrocarbon there corresponds, in principle, a perchlorocarbon of the same structure and configuration. Consequently, the perchlorocarbons can be aromatic, alkaromatic, or aliphatic in character. Until recently, however, comparatively few examples of such compounds were known. Attempts to develop systematic synthetic procedures had been unfruitful, and it was generally believed that these compounds -- save for a few corresponding to the simplest hydrocarbons--could not exist. Stereochemical considerations lend plausibility to this view: the chlorine atoms, much larger than hydrogen, must touch or interpenetrate one another as they bond to typical carbon skeletons.

Prof. Manuel Ballester, of the University of Barcelona, has lately succeeded in producing a large number of these compounds, and has opened up this field to experimental investigation. This breakthrough culminates several years of research by Prof. Ballester, started during a sabbatical residency at ARL's Chemistry Research Laboratory in 1961-62, and subsequently supported by ARL after his return to Barcelona.

The key to success was the discovery of a powerful chlorinating reagent--a mixture of sulfuryl chloride, sulfur monochloride, and aluminum chloride--which converts hydrocarbons to perchlorocarbons by replacing all of the hydrogen atoms with chlorine atoms, yet does not rearrange the molecular backbone. Among the resulting products have been some fairly complex compounds with high thermal and chemical stability. For example, one such molecule, perchlorostilbene, $C_6Cl_5CCl = CClC_6Cl_5$, is unchanged either by heating above 500°C or by boiling in fuming nitric acid for 5 days. Prof. Ballester has also found a new polymerization reaction wherein perchlorocarbons containing the trichloromethyl group, $-CCl_3$, can be coupled together by reducing agents, such as iodide ion or tin(II) chloride, to give polymeric molecules containing the $-CCl = CCl-$ linkage. Such polymers, obtained in molecular weights above 30,000, show thermal and chemical stabilities comparable

Figure 1. Scale model of the perchlorotriphenylmethyl radical. This substance has a structure like a three-bladed propeller; the view in the photo is along the axis of the shaft. The central carbon atom, site of the unpaired electron, is shielded by the large chlorine atoms (light grey spheres). All tunnels of access have subatomic dimensions; hence, this molecular fragment is not easily destroyed by additional reactions involving the "free bond."

to those of the smaller molecules. Development work is now in progress, under both independent and Air Force-sponsored industrial programs, to produce useful materials from these compounds.

Another valuable result of Prof. Ballester's work has been the discovery that the large bulky chlorine atoms in the perchlorocarbons can stabilize free radicals by physically preventing them from contacting other reactive substances. For example, triphenylmethyl is an exceedingly active molecular fragment which reacts with oxygen, chlorine, nitric oxide, and other such species. The perchloro analog, $(C_6Cl_5)_3C\cdot$, while still a free radical, is extremely inert and does not react at all with the compounds just mentioned. (See Figure 1.) The odd electron, the site of reactivity, is completely blocked off from its external environment. The "bottled-up electron" has already been put to practical use as a standard for the calibration of electron-resonance spectrometers.

Polymers have been prepared from these free radicals leading to the first polymeric polyfree radicals known. They are magnetic, appear to have semiconduction properties, and may eventually culminate in the first organic semiconductors to be prepared. It is possible that the free radical polymers may also exhibit metallic properties and, as such, constitute an entirely new class of materials, organic metals or metalloids. The free radicals have been found to undergo electron-transfer processes. This phenomenon suggests the possibility of the use of polymeric radicals in the development of a new type of lightweight inexpensive storage battery containing no metallic plates.

Partial credit for this achievement must be attributed to Dr. Leonard Spialter of the ARL Chemistry Research Laboratory. He contributed to the formulation of the problem and collaborated actively with Prof. Ballester in the early stages of the work and in its subsequent development. OAR is particularly proud of this project as an example of the value and importance of a viable in-house research capability.

OXIDATION RESEARCH

chemistry

Compounds containing unsaturated hydrocarbon groups are important in products as diverse as hydrocarbon fuels, lubricants, auto exhaust, natural and some synthetic rubbers, edible and (paint) drying oils, and Vitamin A. They are the starting materials for vinyl polymerizations. All of these materials oxidize spontaneously in air, the resulting changes are usually, but not always (paints and petrochemicals), undesirable.

Unsaturated hydrocarbons absorb oxygen to give three types of products: (Type 1) allylic hydroperoxides, where the indicated hydrogen atom in $\rangle C{=}C{-}\overset{H}{C}{-}$ is replaced by a hydroperoxide group (-OOH); (Type 2) polymeric peroxides, with the repeating unit, -C-C-O-O-; and (Type 3), mixtures of epoxides, aldehydes, and ketones. The first type of reaction is common in nondrying oils and in rubbers; the second presents purity and explosion problems with styrene and butadiene; the third is important to the petrochemicals industry. All of these oxidations are free-radical chain reactions, subject to acceleration by light and free radicals and to retardation by antioxidants. While many oxidations of unsaturated compounds exhibit mostly one type of reaction to give products listed under Type 1, Type 2, or Type 3, a few show two or three different reactions. Even minor contributions of one type of oxidation may be important. For example, while rubbers oxidize mostly by the first route, whether they harden or soften on aging depends on the relative contributions of the minor second and third types of oxidation.

One of the most important gaps in our knowledge of oxidation phenomena is a basic understanding of how oxidation proceeds under mild conditions. With AFOSR support, Dr. Frank Mayo, the recipient of the 1967 American Chemical Society Award in Polymer Chemistry and a member of Stanford Research Institute, has made a systematic study

of the relation between structures of simple representative unsaturated hydrocarbons and their mechanisms of oxidation under mild conditions. Very little such important information was previously available. The accompanying Table summarizes some of Dr. Mayo's results.

In general, cyclic unsaturated hydrocarbons react fairly rapidly to give mostly hydroperoxides -- but the eight-membered ring cyclo-octene and the bicyclic norbornene are notable exceptions. All the open-chain compounds tested with internal double bonds react faster than those with terminal double

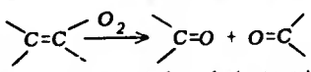
RATES AND PRODUCTS OF OXIDATION OF ALKENES AT 50-90°

Alkene	Product Distribution: Allyl substitution[a]	Product Distribution: Polyperoxides[b]	Product Distribution: Epoxides, cleavage products[c]	Relative rates[d] at 70°
Cyclopentene	79	20	1	0.61
Cyclohexene	82	7	1	0.47
Cycloheptene	69	24	7	0.33
Cyclo-octene	17	25	58	0.078
Cyclododecene	69[e]			0.157
Vinylcyclohexane	83	8	9	0.076
Methylenecyclohexane	49	19	32	0.090
Cyclododecatriene		100[f]		0.29
Propylene	18-77[g]	59-0[g]	25	
1-Butene	63	27	10	0.066
2-Butene	23	37	40	0.106
Isobutylene	16	36	48	0.063
Trimethylethylene	27	49	24	0.21
Tetramethylethylene	49	22	29	1.16
2-Methyl-1-pentene	32	45	23	0.059
t-Butylethylene	0	21	79	0.022
Neopentylethylene	35	29	32	0.019
3-Methyl-1-butene	89	9	2	0.100
1-Hexene	49	42	9	0.034
1-Hexyne	56	29	15	0.18
3-Hexyne	92	5	3	1.4
NorLornene	0	82	18	0.40

[a] *Mostly hydroperoxides, but includes related allylic alcohols and α, β-unsaturated aldehydes or ketones.*

[b] *Includes polyethers and nonvolatile condensation products.*

[c] *Includes aldehydes and ketones resulting from cleavage of alkene at double bond:*



[d] *(Rate constant for chain propagation) / (rate constant for chain termination) ½ in moles/liter and hours, calculated from over-all rate and known rate of chain initiation, and corrected from 50–90° to 70°.*

[e] *Hydroperoxide by titration.*

[f] *Mostly polyfunctional products by intramolecular chain propagation.*

[g] *The two values assume that the residue is all polyacrolein, or all polyperoxide, respectively.*

bonds. In the series, 2-butene, trimethylethylene, tetramethylethylene, the rates and yields of hydroperoxides increase regularly in the same order. Among the vinyl compounds, the yield of allylic hydroperoxides depends, at least partly, on the number and reactivity of allylic hydrogen atoms (hydrogen atoms which are tertiary, or on cyclohexane rings being reactive and methyl hydrogen atoms being unreactive). The proportions of Type-2 and Type-3 products vary considerably, and depend partly on oxygen pressure. Propylene and isobutylene give large proportions of unidentified and therefore unexplained residues.

Since unsaturated hydrocarbons are generally the principal products of oxidations of saturated hydrocarbons, the results obtained will be useful in better understanding a variety of oxidations. This information is useful to the Air Force, since oxidations are a major cause of deterioration of fuels, lubricants, elastomers and organic materials in general.

mathematical sciences

THEORY OF SPHERICAL PLASMA PROBES

The plasma probe is an important tool for the determination of the energy distribution of the charge carriers in a plasma. Qualitatively, the working of a plasma probe is easily understood. For a negative probe potential, for instance, the probe will repel electrons and attract ions. Whether a certain electron reaches the probe depends upon its energy. If the repellent potential is large, only electrons with high energy are able to reach the probe and to contribute to the probe current. Thus it is possible to determine the energy distribution from a probe characteristic, i.e., from a curve of the probe current versus the probe voltage. Of course, the attracted carriers contribute to the probe current, too. Therefore, a clear-cut evaluation of probe characteristics is possible only if the contribution of the current of the attracted carriers can be eliminated. This is indeed possible, provided that the electric field around the probe has certain simple characteristics. If these prerequisites are not satisfied, one may be led to erroneous conclusions.

Investigations have been conducted by Dr. Karl G. Guderley of the Applied Mathematics Research Laboratory, ARL. They have the aim of defining, for different operating conditions (probe radius, probe voltage, ratio of energy of electrons and ions), the character of the field around the probe. The basic element of these investigations is the computation of the field around the probe for a given probe potential and a given probe radius at a given energy ratio. This is by no means a routine task, since one has a nonlinear differential equation which depends, in a very complicated manner, upon a number of parameters which are determined by the solution itself. In this context, a technique described on page 30 of OAR Progress '65 has proved extremely valuable. From inspection of such a solution, one can define different operating regimes.

Figure 1 shows a graph of operating conditions for an energy ratio of the attracted to the repelled carriers of 2 : 1. The horizontal co-ordinate is the probe radius made dimensionless with a Debye length characterizing the plasma. The vertical co-ordinate gives the probe potential made dimensionless with the energy of the attracted carriers. Probe theory in its simplest form can be applied with certainty underneath the curve, CAB, and possibly underneath the curve, EAB. In the triangle, CAE, capturing of particles by the probe is possible; i.e., in this triangle, there is some doubt whether the assumptions made in the theory are applicable

The information generated in these investigations will be useful in a more penetrating analysis of probe measurements.

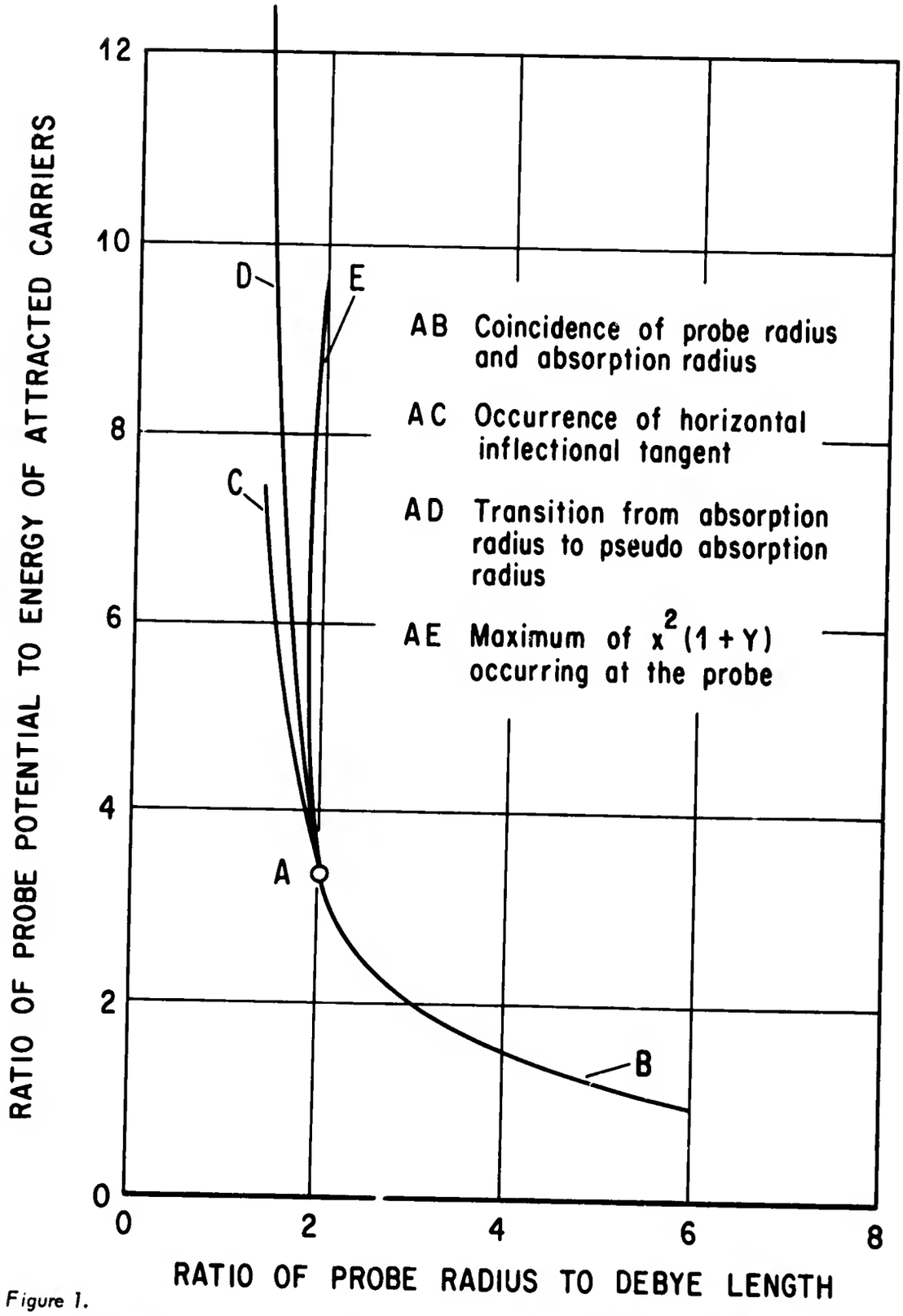


Figure 1.
Graph of operating conditions for the ratio of attracted to repelled carrier energies of 2:1.

CONTROL OF UNSTABLE MECHANICAL SYSTEMS

Unstable mechanical systems constitute a class of dynamical systems which have been of increasing interest to control-theory engineers over the past decade. The most noteworthy example of such a system is a steerable rocket vehicle during its launch phase. Aerodynamically unstable at low speeds, such a vehicle requires a sophisticated control mechanism to insure that it follows the desired trajectory. The present tempo of successful launches and missions indicates that sufficiently sophisticated controllers have been designed for today's vehicles; but it is not clear that contemporary techniques will suffice for the future.

For example, the continuing stress on maximizing the payload/booster mass ratio indicates that future missiles may be significantly more flexible than those presently in use. This eventuality would seriously compound the controller problem, for then the guidance system must not only maintain vehicle attitude and adherence to the desired track, but must also control the complex interbody motions allowed by flexibility.

A study was made of the effects and ramifications of extreme flexibility of a relatively simple unstable mechanical system on the control and controllability of that system. In this study, the device shown in Figure 1 was constructed and operated for extended times. The model consists of a motor-driven cart to which is hinged a highly flexible beam. The cart motor is controlled so as to drive the cart horizontally and thus balance the beam vertically. Such a device is inherently unstable and imposes controller requirements quite similar to those generated by the flexible booster discussed above.

This experimental study by Captain John F. Schaefer of the Aerospace Mechanics Division, FJSRL, has yielded several significant results. Among them was the realization that a control thruster (cart motor) of limited output could not only balance the beam, starting from sufficiently small initial con-

Figure 1. Experimentally controlled limber beam.

ditions, but could also dampen motions due to an arbitrary number of the beam's bending modes. Systematic techniques for synthesizing a feedback-control law to actively control any number of such modes were developed.

A portion of the analysis was devoted to a study of the behavior of the experimental system as the beam's structural stiffness was (mathematically) varied. It was found that, at certain low values of structural rigidity, the assembly could not be controlled, regardless of the horizontally directed thrust levels available. This result is readily extendible to the problem of controlling the bending motions of a flexible missile, and indicates that certain combinations of structural stiffness and longitudinal accelerations must be avoided if lateral stability is to be achieved by thrust-engine gimballing alone.

TRAJECTORY OPTIMIZATION

mathematical sciences

There are many problems in the field of trajectory optimization and optimal control that are of Air Force interest. One such problem concerns aircraft performance where the objective may be to maximize range, or minimize the time-to-climb of an aircraft within selected constraints. Another concerns injection of a pay load into a given orbit while minimizing the propellant. For such a problem one must determine the best programming of the angle of thrust, the optimal time to initiate coasting, and the length of the coasting intervals.

These problems and others in many other fields can be formulated in identical mathematical terms. The resulting mathematical formulation is amenable to treatment by the calculus of variations, or by the recent theory of the maximum principle. However, in general, these theories do not lead directly to the solution of the original problem. Instead, they lead to another, nearly equivalent problem, the two-point boundary-value problem.

In the past, these problems have usually been solved by methods of trial and error. Within the last few years, a number of computational procedures aimed at solving these problems have been developed. One of these techniques is called the method of steepest ascent, and is particularly adapted to digital-computer solution of these problems. This method generates a sequence of approximations to the optimum solution which, in general, is a continuous function of time.

Major Rinaldo F. Vachino of the Aerospace Mechanics Division, FJSRL, has been investigating extensions of the method of steepest descent. His results indicate that the preceding theory is applicable to a number of realistic problems that have limitations on the controls. Such a class of problems is said to have inequality constraints on the control variables. In the presence of these constraints, a wide class of problems has optimum solutions which are no longer continuous functions of time; instead, they are composed of a finite number of segments or functions, each of which is continuous, and joined together according to given rules. The times at which the control function switches from one to another of these adjacent segments are called switching times. Each of these segments is called a subarc.

The present research shows that the method of steepest ascent may be extended to solve two general classes of problems. The first class comprises those problems whose optimum solutions are composed of a known number of subarcs, each of which obeys known differential equations and constraints. The second class includes those problems whose optimum solutions are composed of an unknown number of subarcs, each of which must obey differential equations that belong to a certain class of equations.

The results have been found to be of practical Air Force application in problems of the short-term prediction of the positions of orbiting satellites, of tactical air-to-air interception, of returning from an interplanetary flight and landing at a predetermined position on the earth, and of the optimization of the flight path of a multistage vehicle.

NUMERICAL INTEGRATION OF NAVIER-STOKES EQUATION

The Navier-Stokes equation, which describes the motion of a disturbed viscous fluid, is extremely important in many areas: flow about aerospace vehicles in flight, flow in a tube or channel, and many others. Unfortunately, it is a nonlinear, elliptic, partial differential equation. While a considerable number of results on estimates and bounds of solutions have been obtained analytically, there has been a need for detailed, numerical results.

Working under a grant from the Applied Mathematics Division, AFOSR, Prof. J. Gillis of the Weizmann Institute of Science has developed methods for numerical integration of this equation. To demonstrate these methods, he obtained detailed solutions for the flow of a viscous fluid in the inlet region of a straight channel, including the case of an electrically conducting fluid in the presence of a transverse magnetic field. The problem was solved for a large range of Reynolds numbers, magnetic Reynolds numbers, and Hartmann numbers. In the course of obtaining these solutions, hitherto-unknown behavior of the velocity profile was discovered.

These results have a wide range of applications, particularly in hypersonic-wind-tunnel and fluid-control systems. They have been transmitted to several groups, and have been utilized, particularly by the University of Tennessee Space Institute, in connection with work being performed for the Arnold Engineering Development Center, AFSC.

ASYMPTOTIC EXPANSIONS FOR ORDINARY DIFFERENTIAL EQUATIONS

A good example of the implementation of the mathematical community's and Government's responsibility for the exchange of information may be found in the series of research monographs sponsored by the Mathematics Division, AFOSR. This series reflects a special program initiated to stimulate the writing of noteworthy monographs designed to bridge the gap between the professional mathematician and the user of mathematics. It is an excellent vehicle for enhancing the effectiveness of our national scientific and technical effort and the efficiency of Government management of research and development, for it presents an effective method for communicating information about current research efforts and the results of past efforts.

For instance, Professor Wolfgang Wasow, of the University of Wisconsin, has recently completed an outstanding book entitled Asymptotic Expansions for Ordinary Differential Equations. The reader will recall that asymptotic series are series which diverge, but which are nevertheless useful in the sense that a finite number of terms gives a numerical value whose error is known. That is, asymptotic series give one a means for approximating a desired function with a finite series of terms plus a remainder whose maximum magnitude is known. It will be observed that the error cannot be made arbitrarily small with such a series; however, the error is often so small that asymptotic series are frequently more accurate than other practical expansions.

The importance of asymptotic series in the theory of differential equations was recognized in the second half of the nineteenth century, and a substantial part of our present knowledge was developed during those decades. However, only in recent years has it become apparent how essential asymptotic series are to an understanding of the structure of the solutions of ordinary differential equations, and how inescapably they arise in

many questions of applied mathematics. The number of physical problems in which such series are, or could be, used to advantage is large and growing. The list includes many questions of quantum mechanics, viscous flows, elasticity, electromagnetic theory, electronics, astrophysics, and other fields.

In his book Professor Wasow has developed, in a connected way, the mathematical methods of this field. The selection of subjects reflects the author's interests and experience. Special differential equations and special functions are introduced as examples for general theories. Also, fascinating applications to physical problems and the computational aspects are discussed. Throughout, the emphasis is on the mathematical ideas underlying the various methods.

Although the book is not a compendium on the subject, its bibliography, with well over 200 citings from journal articles and books, gives an indication of the depth in which this subject is treated.

This research monograph will be a valuable aid to the applied scientist, for it presents an extremely clear and succinct treatment of asymptotic expansions. Such types of expansion are quite useful in representing solutions of a variety of equations arising in aerodynamics, control theory and communication theory, as well as the more sophisticated equations of contemporary physics. The latter promise to play a dominant role in future developments in physics and, in turn, to significantly influence the future development of Air Force science and technology.

COMPUTER SELF-DIAGNOSIS

electronics

In any computer system, it is vitally necessary to be able to determine whether or not the computer is functioning correctly. Failures in one or more elements may permit the computer to continue to operate, but cause the results of that operation to be worthless by making the computations erroneous. This can be of particular significance in computers used in aerospace vehicles for such functions as bombing and fire control, and for attitude and trajectory control. If a computation is in error, the result can be complete failure of the mission, or even loss of the vehicle. Thus, a rapid method of locating computer malfunctions, and of diagnosing the cause of these malfunctions, would be extremely valuable in improving the reliability and capability of computers used in aerospace applications.

The Coordinated Science Laboratory (CSL) of the University of Illinois, supported by the Electronics Division of AFOSR, through the Joint Services Electronics Program, has been investigating the problem of computer self-diagnosis. Drs. E. Manning and D. Compton, of this Laboratory, have devised a procedure for self-diagnosis of digital computers, based on the CSX-1 computer developed at CSL. This procedure has been tested and shown feasible.

In operation, the self-diagnosis procedure consists of a short program which is loaded into the computer and started running. If the program runs to completion, this is a necessary and sufficient condition that there are no failures in the system (or that, if any element has failed, it has been supplanted by a redundant back-up element), and that therefore the computations of the computer are correct. In the event of a failure of the program to run to completion, a fault is present in the computer. The computer operator then determines the contents of the program registers of the computer (this is a simple printout process), and consults a handbook which provides a manual procedure to be implemented on the computer. Execution of this manual procedure will permit diagnosis of the fault.

The procedure for self-diagnosis was tested by simulating the CSX-1 Computer on a Control Data Corporation 1604 Computer, with failures of some of the elements included in the simulation (this was a simpler procedure than introducing genuine element failures in the CSX-1). The experiments showed that self-diagnosis was feasible,

and that the execution hardware could be checked in a fraction of a second with, at most, a few minutes of additional time required for the fault-locating procedure (if, in fact, the diagnosis showed that the computer was not fault-free). The techniques used for self-diagnosis and fault location appear to be applicable to a variety of computers although, because of differences in hardware and design, each computer will require a different self-diagnosis program. Successful demonstration of the program on the CSX-1, however, gives considerable confidence that similar procedures can be devised for computers which will be used in aerospace vehicles.

electronics

ELECTRICAL CONTROL OF LIMB PROSTHESIS

Externally powered prostheses have been studied for many years, in an effort to provide rehabilitation of amputees. In order to take full advantage of the benefits offered by external power in prostheses, the mode of control of the prosthesis by the amputee must also be improved. Currently used control methods require a high degree of mental concentration by the amputee, because the mode of control of a prosthetic motion is different from control of the corresponding thermal action, and because there is no feedback of sensation from the prosthesis to the patient, except through the visual sense.

Bioelectric control offers the possibility that control of the prosthetic action can be similar to that of the corresponding body action, which was lost through amputation. The muscles in the body produce an electrical signal, called the electromyogram (emg), which can be sensed directly from the surface of the skin. Several experimental prostheses have been developed previously which use emg signals for control purposes. The major shortcoming of most of these devices has been the lack of graded control of their behavior.

Under the supervision of Professor A. G. Bose, and with the sponsorship of AFOSR, Ralph Alter, of the Massachusetts Institute of Technology, has developed a system which utilizes surface emg signals from the biceps and triceps of an amputee's arm to provide graded control of an elbow prosthesis. The development included as an intermediate step the control of a simulated forearm in a digital computer, in real time. In its present form, the signal processing consists of full-wave rectification and low-pass filtering of the emg signals from biceps and triceps muscles. An actual mechanical-elbow prosthesis has been voluntarily controlled through the subject's emg signals. The mechanical design was carried out under the supervision of Professor Robert Mann, of the MIT Mechanical Engineering Department.

Besides medical applications, this scheme has application to devices for adaption to normal subjects where graded mechanical assistance to normal movements is needed, such as in high "g" environments, or when working against high pressures or in very dense environments.

EROSION JETS

electronics

When a current jumps across the air gap from a cathode to an anode, the resultant spark discharge usually erodes both the cathode and the anode through simple thermal evaporation. Recently, an AFCRL scientist, Dr. Heinz Fischer, observed another erosion process -- one predicted but never seen before.

This phenomenon was first observed in the afterglow of a high-current plasma light source, called the Nanolite, developed at AFCRL. The Nanolite produces extremely brilliant pulsed light with a duration measured in nanoseconds (billionths of a second). Photographs of the afterglow of the spark discharge showed that, at approximately

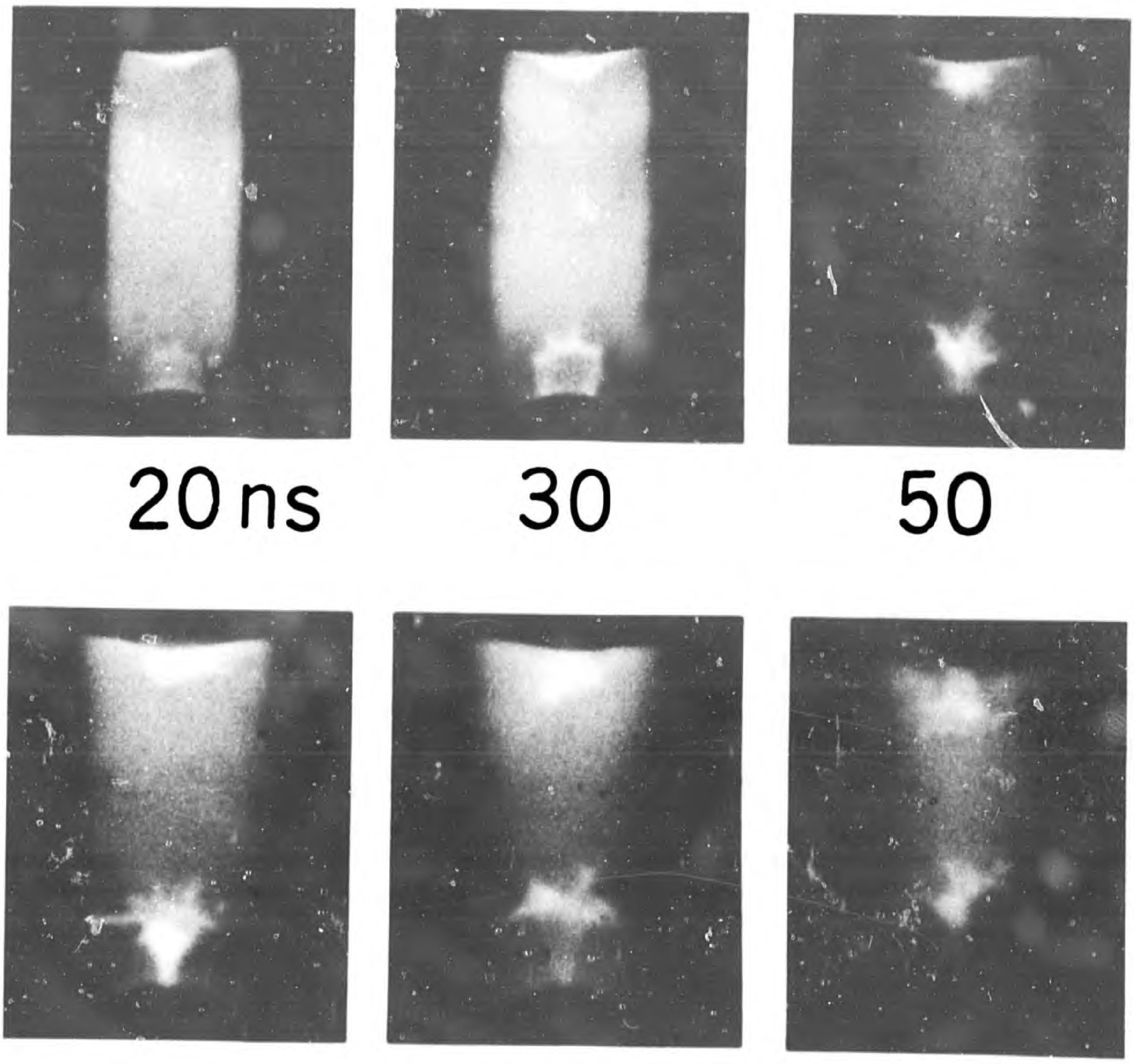


Figure 1. Evolution of anode erosion, 20 nanoseconds to 120 nanoseconds.

30 nanoseconds after the current had ceased, a jet of material literally explodes from a small, discrete point on the surface of the anode. This jet, lasting about 120 nanoseconds, resembles a water fountain -- or, to some extent, the mushroom cloud of a microscopic atomic explosion.

Although this effect has not previously been observed, theory predicts that a fountain of material could be ejected from the tip of the anode as a result of "electron overpressure." Electron overpressure, an explosive condition resulting from too many electrons being squeezed into a small volume, could occur in an arc lamp's anode immediately after a flash. Such an explosive excess of electrons would likely build up in the anode of the light source because of its small diameter (0.05 millimeter) and the large current of several thousand amperes which flows from cathode to anode in a few nanoseconds. Like charges repel each other and,

as the concentration of electrons expands, it knocks out minute chunks of electrode material. Because of the short current times, only small amounts of material are ejected, and the effect on the useful lifetime of the electrode, though as yet undetermined, is probably small.

However, evidence is indirect that the fountain-like ejection discovered by Dr. Fischer is the result of electron overpressure. Emission spectra taken of the clouds have not shown any lines characteristic of the electrode material. This lack of spectral lines indicates that the material in the clouds is not in the vapor state. Thus, the fountain-like clouds are different from the usual form of electrode erosion in which material from the electrode surface is vaporized by the high temperature generated by the passage of electric current. In Dr. Fischer's experiments with the Nanolite, the current pulses, which lasted only 10 nanoseconds, were much too short to cause vaporization of electrode material.

The discovery of such electrode-erosion processes could have a bearing on certain studies of controlled thermonuclear power. Several devices now being studied make use of high current discharges to heat the deuterium plasma. Even the slightest contamination of this plasma by impurities can cause an intolerably high loss of thermal energy through radiation by the contaminating material. Contaminating material could be introduced into the plasma by electrode erosion caused by electron overpressure.

electronics

IMPEDANCE LOADING—A METHOD OF CONTROLLING SCATTERED ELECTROMAGNETIC FIELDS

Whenever an electromagnetic wave strikes a conducting object, currents are induced on the surface of the object, and these currents radiate, maintaining distant fields much as though the object were a transmitting antenna. These fields that are maintained by the induced currents are called scattered fields; their quantitative measure is called the scattering cross section of the object, and is defined by

$$\tau(\theta,\phi) = \lim_{r\to\infty} 4\pi r \left| \frac{E_s}{E_{inc}} \right|^2 ,$$

where E_{inc} is the incident electric field at the object, E_s is the far-zone scattered field, and r indicates distance from the scatterer.

The fields which are indiscriminately scattered by metallic objects are nearly always undesirable, and many attempts have been made to find methods for controlling them. One new and promising method which has recently been investigated by AFCRL is "impedance loading." At low frequencies, the currents in various branches of a conventional circuit are controlled by the branch impedances. Similarly, at microwave frequencies, the equivalent of small lumped loading impedances may be placed in the surface of the scatterer. These impedances act as Thevenin generators, maintaining currents that are proportional in phase and amplitude to the load impedance and the current induced at the load. The total scattered field of an impedance-loaded scatterer is partially due to the undisturbed current induced on the object, and partially due to the redistributed current maintained by the load, so that

$$E_s(\theta,\phi) = E_0(\theta,\phi) + E_1(\theta,\phi)\frac{Z}{Z+Za},$$

where E_s is the total scattered field, E_0 is that part of the field due to the unloaded scatterer, and E_1 is that part of the field due to the load. Z is the load impedance and Z_a is the antenna impedance -- the input impedance if the object is driven as an antenna with driving-point terminals identical to the loading terminals. Clearly, if the load impedance is adjusted until

$$E_1(\theta,\phi)\frac{Z}{Z+Za} = -E_0(\theta,\phi),$$

the scattered field will vanish.

These ideas have been applied to a number of objects, such as thin rods, thick rods, flat plates, spheres and polyhedra, and the results indicate that the scattering can generally be reduced by at least 15–20 db from that of the unloaded object. At microwave frequencies, the actual loading impedance may take many forms such as a cavity-backed aperture, a small antenna, or even conventional coils and capacitors.

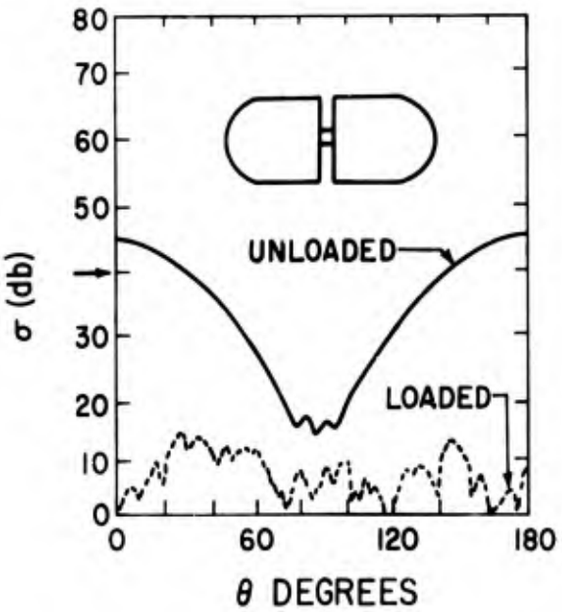


Figure 1. Backscatter cross section from impedance-loaded and unloaded metal rod.

Typical results that can be obtained from a short thick rod are shown in Figure 1. In this case, the load impedance was a cavity-backed ring aperture at the center of the rod. The rod was approximately $\lambda/2$ in length and $\lambda/4$ in diameter, and the incident electric field was polarized parallel to the rod axis. In Figure 1, backscatter cross sections in the broadside directions have been reduced by about 30 db with loading.

Figure 2 illustrates the reduction obtained at normal incidence to planar surface consisting of a set of small square plates connected with a network of conventional coils and capacitors.

Many additional details and results are discussed in references (1) and (2), and in the bibliography of reference (1).

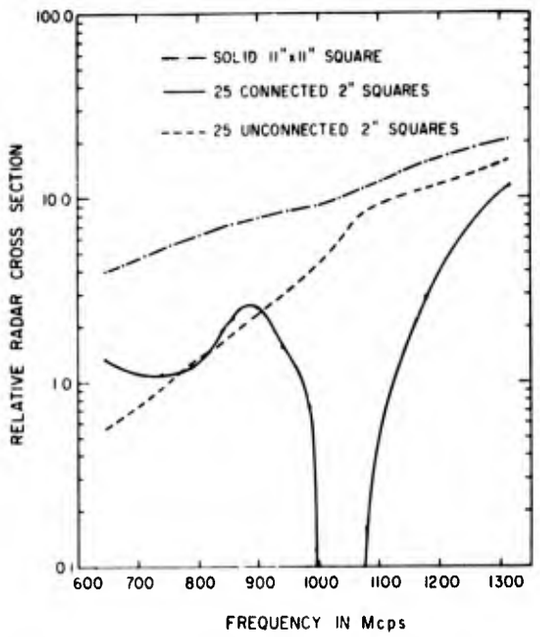


Figure 2. Backscatter from impedance-loaded and unloaded square plates (from Flood, D. P. and J. C. Field, Final Report, "Experimental Study of the Backscattering from Conducting Objects in the Range of One Quarter to One Wave Length in Size," Andrew Alford Consulting Engineers, Contract AF 19[628] 2456, AFCRL 64-541, April 1964).

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PHONONS, MAGNONS AND COUPLED TRANSMISSION LINES

A new insight into magnetic-wave propagation in single-crystal materials has been provided by James C. Sethares of AFCRL. His model involves a coupling process between the magnetic and acoustic waves in an energized ferrite crystal. Essentially, the model provides a more convenient mathematical method for calculating the energy density of magnetic waves.

The quantum terms for magnetic and acoustic waves are magnons and phonons, respectively. Only microwave magnons and phonons, having wave lengths on the order of 1 to 10,000 angstrom units, are of interest in the Sethares study. When magnon and phonon waves are of equal length, energy exchange between them is possible. Because of the small wave lengths involved, a very large number can be accommodated in a single-crystal specimen an inch or so long. The crystal can thus be considered a transmission line. Propagation conditions of magnons and phonons in the crystal are found to be similar to those encountered in coupled transmission-line theory. Coupling exists when power can be transferred from one line to another.

The Sethares model consists of two coupled transmission lines, one for the magnon mode, the other for a phonon mode. This model is believed to be the first of its kind. Its unique feature lies in the choice of variables used to describe magnon-wave propagation, which are chosen in analogy to those for phonon-wave propagation. Phonon waves are generally described by force and velocity fields, proportional, respectively, to spatial and temporal derivatives of displacement. The product gives the energy density carried by the phonon.

Magnon waves may also be described by two vector fields, proportional, respectively, to spatial and temporal derivatives of magnetization. The product of the fields gives the energy density carried by the magnon. Voltage and current along the transmission lines are taken to be proportional to the spatial and temporal derivatives of magnetization and displacement. Distributed inductive and capacitive coupling may exist between lines.

One of the benefits of the model is that it permits the microwave physicist to draw from known results of coupled transmission-line theory, and to apply these known results to the prediction of new magnetoacoustic phenomena.

The generation, detection, amplification, control, and propagation of magnons and phonons is a relatively new and rapidly evolving field of investigation. The Air Force physicist working in this field enjoys the best of the two worlds of science and technology. As a scientist, he finds himself in a relatively uncrowded field with new analytical techniques for exploring the internal forces and energies of matter in the solid state. But he also sees ready Air Force application of the new knowledge to electronic devices and equipments. The work has high potential for improved delay lines, pulse compressors, and for the generation of coherent radio energy well beyond the 50-gHz range.

ION IMPLANTATION: A NEW SEMICONDUCTOR PROCESSING TECHNIQUE

The objective of the ion-implantation-research effort is to determine the feasibility of implanting energetic ions (50 KeV to 3 MeV) into semiconductors for the purpose of doping or otherwise controlling the properties of these materials. The results of these studies, if completely successful, hold vast potential in the development of new solid-state devices, new device principles, and new manufacturing techniques of considerable importance to the Air Force.

During the past year, the work of R. Dolan

and S. Roosild of AFCRL has been devoted to the problem of introducing the common impurity dopants into silicon and other semiconductors via high-energy ion-implantation techniques. The major evaluating factor for successful implantation has been the electrical properties of the p-n junctions so formed. Boron and phosphorus ions have been introduced substitutionally into the silicon lattice to form highly satisfactory p-n and n-p junction diodes; i.e., they are comparable in electrical characteristics to those obtained by conventional diffusion methods. The success so far achieved with this technique in the case of silicon makes more attractive the feasibility of forming p-n junctions in higher-band-gap semiconductors with their greater tolerance of high temperatures.

To prove out the above techniques, an attempt was made to determine the feasibility of using the ion-implantation technique to make an active semiconductor device. Utilizing the design- and device-making facilities of AFCRL and the ion-implantation facilities of the Ion Physics Corporation, a prototype field-effect transistor was fabricated. The electrical characteristics of the device were encouraging enough to establish this as a feasible technique for making active semiconductor devices. The improved lateral resolution made possible with this technique will be useful in the development of higher-frequency semiconductor devices.

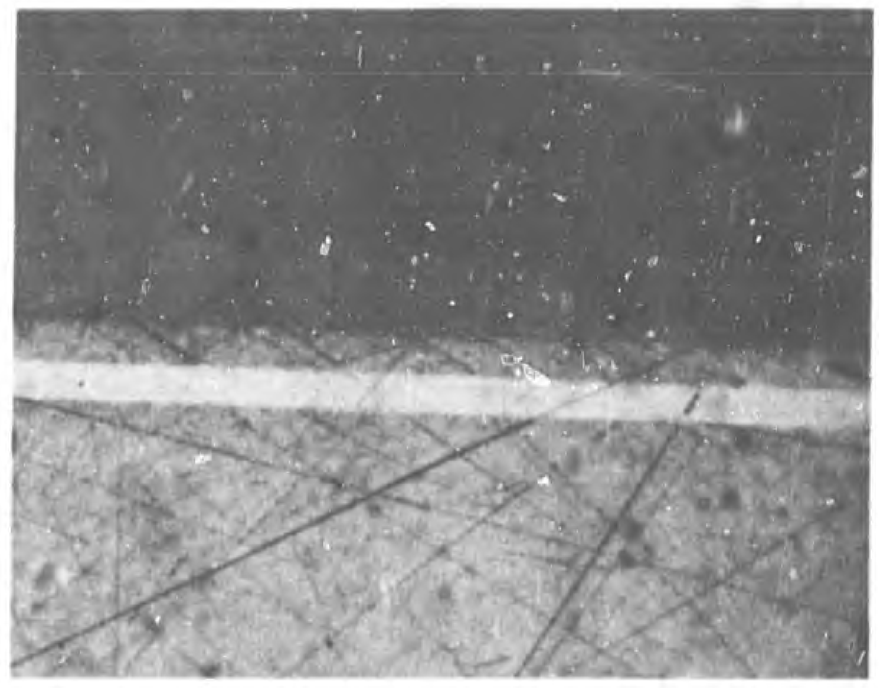


Figure 1. A layer of nitrogen 1.5 microns wide implanted in silicon 2.5 microns below the surface.

Recently, on a wholly in-house basis, nitrogen was successfully implanted into silicon. Although it has long been known that nitrogen should be a dopant in silicon, this is the first time an experimental doping has been accomplished.

electronics

THE GAS LASER— CHALLENGER FOR SUBMILLIMETER-WAVE GENERATION

The submillimeter region (300 to 3000 GHz) of the electromagnetic spectrum has long eluded researchers. Efforts to scale down microwave devices to accommodate these shorter wave lengths have been disappointing in that wave guides become mere capillary tubes limited by short lifetimes, low-output power levels, and high costs. Other ways of generating submillimeter waves, including backward-wave oscillators, masers, nonlinear resistive-inductive-capacitive and ferromagnetic devices, and relativistic electron sources have shown promise, but none of these has met the challenge. Our brightest hope for the eventual generation of radiation throughout the far infrared at significant power levels lies with the gas laser.

At the present time, it is known that a small number of gases, mainly organic, will lase in the 100 to 400-micron range. In fact, many lasing lines are known for water vapor (Fig. 1) and various amines. Professor Paul D. Coleman is conducting extensive research on gas lasers at the University of Illinois, under an AFOSR grant. He has recently reported experimental results on a water-vapor gas laser operating at 118 microns wave length. It consists of a 4-inch-diameter, 2-meter-focal-length mirror resonator system, with a mirror spacing of 3.75 meters. Each half of the gas discharge

was pulsed with a separate modulator capable of delivering up to 8 kilovolts at 300 amperes in a 5-microsecond pulse at repetition rates from 50 to 500 per second. Typical peak power outputs at 1-mm Hg pressure and 3-amps-per-cm^2 current density were in excess of 3 milliwatts. This device, shown in Fig. 2, was used to confirm much of the data in Fig. 1, and will soon be used to study gases and gas mixtures that will yield lasing lines throughout the "forbidden" region.

It is firmly believed that gas-laser work of this type will, at long last, open up the last frontier of the electromagnetic spectrum for research and application. With line sources at the watt level, sufficient power is now available for precision spectroscopy of materials, and detector and transmission studies. Recent results on CO_2 lasers at 10.6 microns, where average powers in excess of 200 watts have been reported, lead one to believe that further work on far-infrared lasers will yield substantially more output.

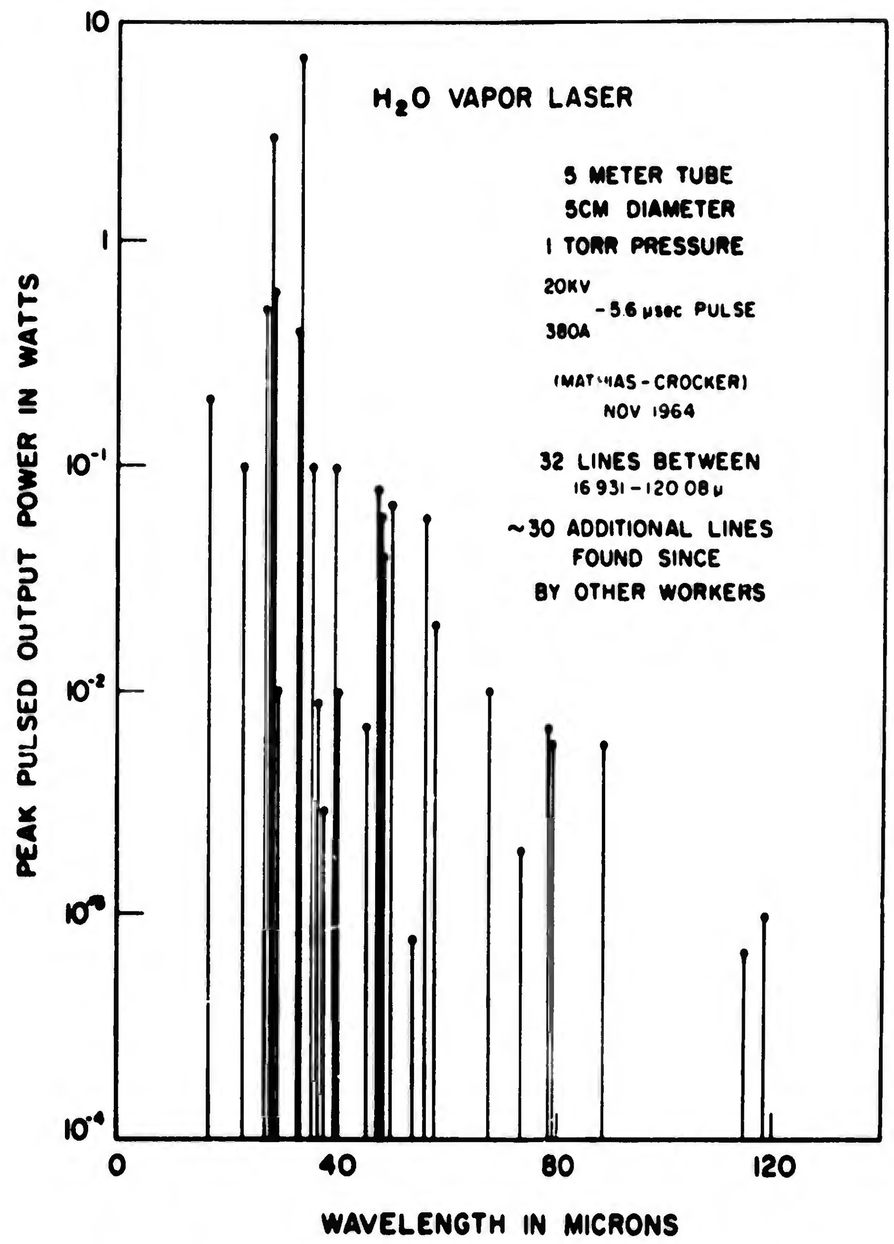


Figure 1. Lasing lines for water vapor.

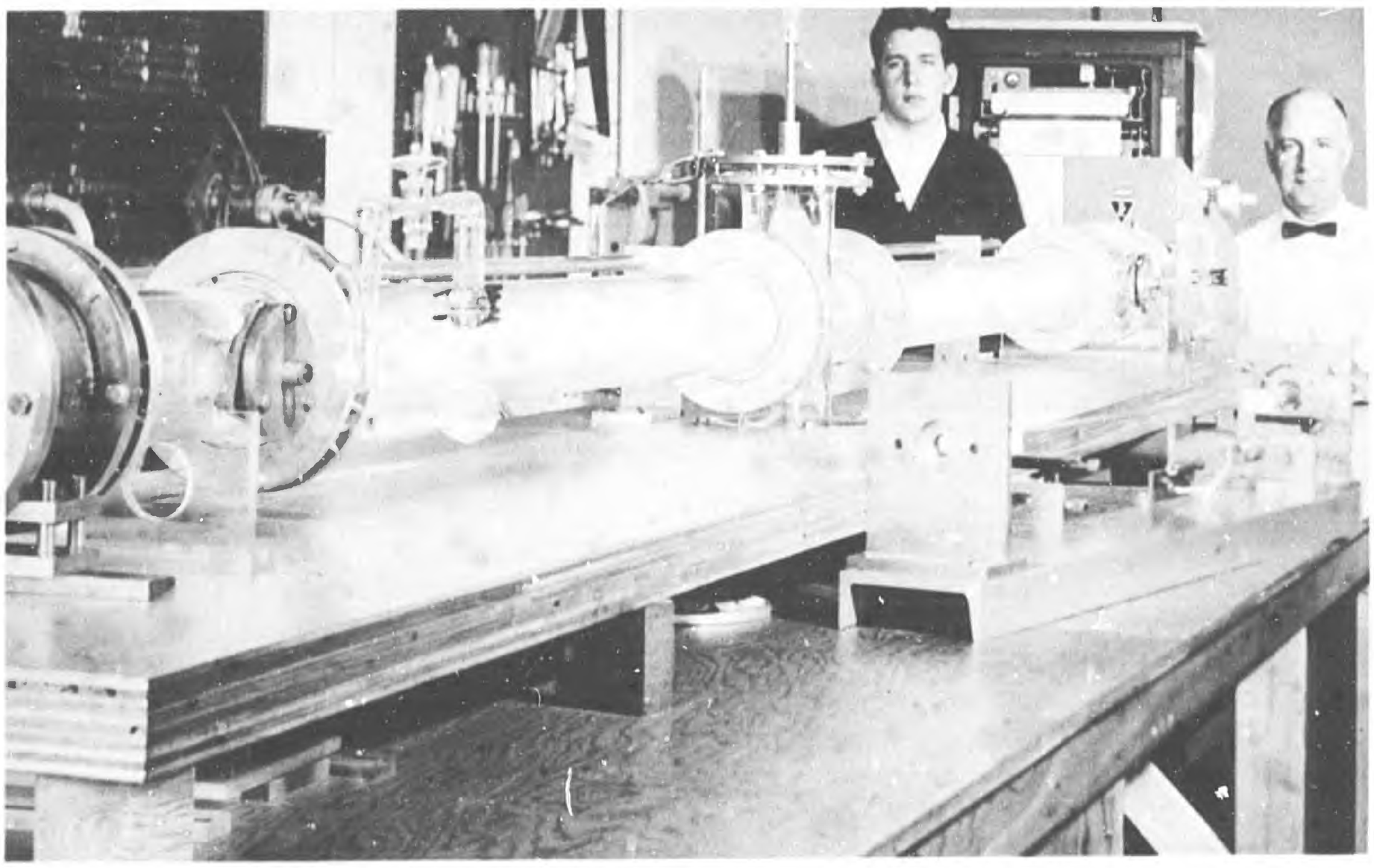


Figure 2. Water-vapor gas laser.

PROGRESS TOWARD HIGH-POWER, HIGH-FREQUENCY LASERS

The production of intense, coherent light through the optical and higher ranges is potentially of great military value in such applications as, for example, secure communications and weapons systems. While considerable success has been achieved using laser techniques to generate light at the red end of the spectrum, theory and experience indicate a very rapid decrease in the efficiency of laser devices toward the violet end of the visible spectrum.

An alternative means to direct production of the higher optical frequencies, which can yield considerably greater efficiencies in this range, is the conversion of efficiently produced laser light to twice its frequency by the techniques of nonlinear optics. Second-harmonic generation has received much scientific attention; and high conversion efficiencies (about 50%) have been achieved by this method, in terms of output power/input power. There have, however, been some shortcomings, in practical terms, because of the extremely critical orientation required to achieve the "phase matching" necessary for full efficiency. The useful materials are severely limited to those that combine the necessary properties.

The approach taken by Dr. Charles Naiman, of Mithras, Inc., in a research program sponsored by AFOSR, has been to utilize controlled absorptions in the harmonic-generating material to increase efficiency under much less stringent conditions than necessary with perfectly transparent materials. Though it has been widely believed that the losses in absorbing media would inevitably overcome any attainable increase in the efficiency of second-harmonic generation, specific conditions have been derived for which this is not the case. Consider a crystal lacking inversion symmetry and doped with metal ions. A weak breakdown of parity, such as that which makes intraconfiguration transitions possible in rare-earth ions, can lead simultaneously to high nonlinearities and week absorptions. Numerical estimates indicate the strength of the second harmonic to be over 1,000 times that of KDP, with absorption coefficients less than 1 cm^{-1}. Efficient conversion is anticipated at low incident-power levels (several kilowatts), with small crystals (about 1 mm) and with less critical phase-matching conditions.

electronics

HOLOGRAPHIC DIFFRACTION GRATINGS—PROGRESS TOWARD THREE-DIMENSIONAL IMAGERY

The distribution of reflected electromagnetic energy over some plane in space is a unique description of the scene which reflects that energy. Thus, if one has knowledge of such a distribution, he also has knowledge of the scene which created it. This phenomenon is especially apparent at optical frequencies; e.g., in photography, we can record information about the scene by using a camera lens to transform a portion of the field information into an image. However, photography involves the recording of amplitude information; phase information, which also arrives at the photographic-system aperture, is lost.

Gabor, in 1948, showed that phase information could also be recorded on photosensitive film if it were first converted to amplitude information via its interference with a reference field of known wave shape. Since interference is a result of an interaction between coherent fields, such a conversion requires that both the reference field and the scene illuminator be coherent sources (laser beams). A photograph (transparency) of a laser-generated interference

pattern is called a hologram. The scene is reconstructed for the viewer when the hologram is reilluminated by that laser frequency used to create it. The viewer then sees the recreated scene in three-dimension (real-life) perspective.

Holograms today are rather crude. A better understanding of the holographic process will precede our ability to produce high-quality film recordings of laser-generated interference patterns. Professor Nicolas George, of the California Institute of Technology, is conducting a detailed study of efficiency and resolution in the production of holograms, under an AFOSR contract. In this endeavor, he has recently produced holograms which were utilized as optical diffraction gratings. (1)

The experimental apparatus used to make the diffraction gratings is similar to that reported by Leith and Upatnieks. (2) Earlier work on interferometric methods for the photographic production of gratings is reported by J. M. Burch and D. A. Palmer (3), and the principal methods for the production of gratings are described by G. R. Harrison. (4)

A wide range of grating spacings is available with the two-beam holographic method, as both the wave length and the angular separation of the two beams can be changed. The grating spacing, or distance between adjacent fringes, is given by

$$d_s = \frac{\lambda}{2 \sin\left(\frac{\theta_2 - \theta_1}{2}\right) \sin\left(\frac{\theta_2 + \theta_1}{2}\right)},$$

where θ_1 and θ_2 are the angles which beams (1) and (2) make with the film plate, and λ is the wave length of the source.

Professor George has produced gratings having 820 lines per mm over a 7-cm x 7-cm surface, using Kodak 649F high-resolution film plates. Two symmetrically incident beams having an angular separation of 30 degrees were used. The light source used was a 5-mw helium-neon laser operated at 6328A. Precautions which were taken to ensure satisfactory results included spatial filtering of both beams, vibration and acoustic isolation, and minimization of the difference in path lengths of the two beams.

materials research

HYDROGEN EMBRITTLEMENT OF IRON AND STEEL

The catastrophic failure of high-strength steel parts in service has been of particular concern to the aircraft and aerospace industry for many years. Many of the failures encountered could be attributed to "hydrogen embrittlement"-- either as slow-strain-rate embrittlement (dynamic loading), or as delayed failure (static loading). Most scientists and engineers have tended to classify both types of embrittlement under the simple heading of hydrogen embrittlement, and proposed mechanisms resulting from investigations of one type have generally been extended to the other. The intent has been to apply one mechanism to all forms of hydrogen embrittlement; but the net result has been one of continuing controversy.

Most workers investigating slow-strain-rate embrittlement conclude that hydrogen atoms escape from solution and combine to form hydrogen gas at areas where voids or low-energy interfaces (such as an inclusion) exist. The gas exerts sufficient pressure within these cavities to cause premature crack propagation when relatively low levels of external stress are applied. However, those workers studying delayed failure on a number of materials with a variety of solutes in addition to hydrogen, conclude that hydrogen is damaging through a lattice effect. They found a quite-reasonable correlation between the strain-aging behavior and the delayed-failure behavior of these materials. Since strain aging involves the interaction of interstitial solutes with dislocations, including upper-lower yield-point behavior, and since rather conclusive evidence exists for a yield point in iron and steel due to hydrogen, one further contribution to embrittlement could be hydrogen-dislocation interactions which favor crack propagation.

The above consideration was the basis

chosen by Mr. A.M. Adair for an investigation at ARL. The significance of hydrogen-dislocation interactions in a zone-refined iron was evaluated by means of the Petch relationship, $\sigma_{LY} = \sigma_0 + k_y d^{-\frac{1}{2}}$, where the lower yield stress (σ_{LY}) is plotted versus the inverse square root of the grain diameter ($d^{-\frac{1}{2}}$). For a range of grain sizes, the resultant plot yields two significant parameters: σ_0, which is a measure of the resistance of the lattice to moving dislocations, i.e., a lattice friction stress; and k_y, which is a measure of the relative ease of initiating macroscopic plastic deformation.

Specimens having five different grain sizes were compared in each of three conditions: (1) cathodically charged with hydrogen; (2) uncharged; and (3) cathodically charged with hydrogen and evacuated to remove the hydrogen. The resulting Petch plots are shown in Figure 1. Upon hydrogen charging, there is a substantial reduction in the slope (k_y), and a substantial increase in the intercept (σ_0). The reduction in k_y and the increase in σ_0 essentially remain when the hydrogen is removed. The ductility, however, is very dependent on the presence of hydrogen. Figure 2 shows the percent elongation plotted versus $d^{-\frac{1}{2}}$ (for convenience only). A significant improvement in ductility results upon hydrogen removal, and complete recovery of ductility is experienced by the two finest grain sizes.

Since the parameters which reflect hydrogen-dislocation interactions (σ_0, k_y) are much more dependent on the fact that hydrogen was introduced cathodically than on the very presence of hydrogen, and since the opposite is true for the ductility, any contribution to embrittlement by hydrogen-dislocation interactions is a very minor effect.

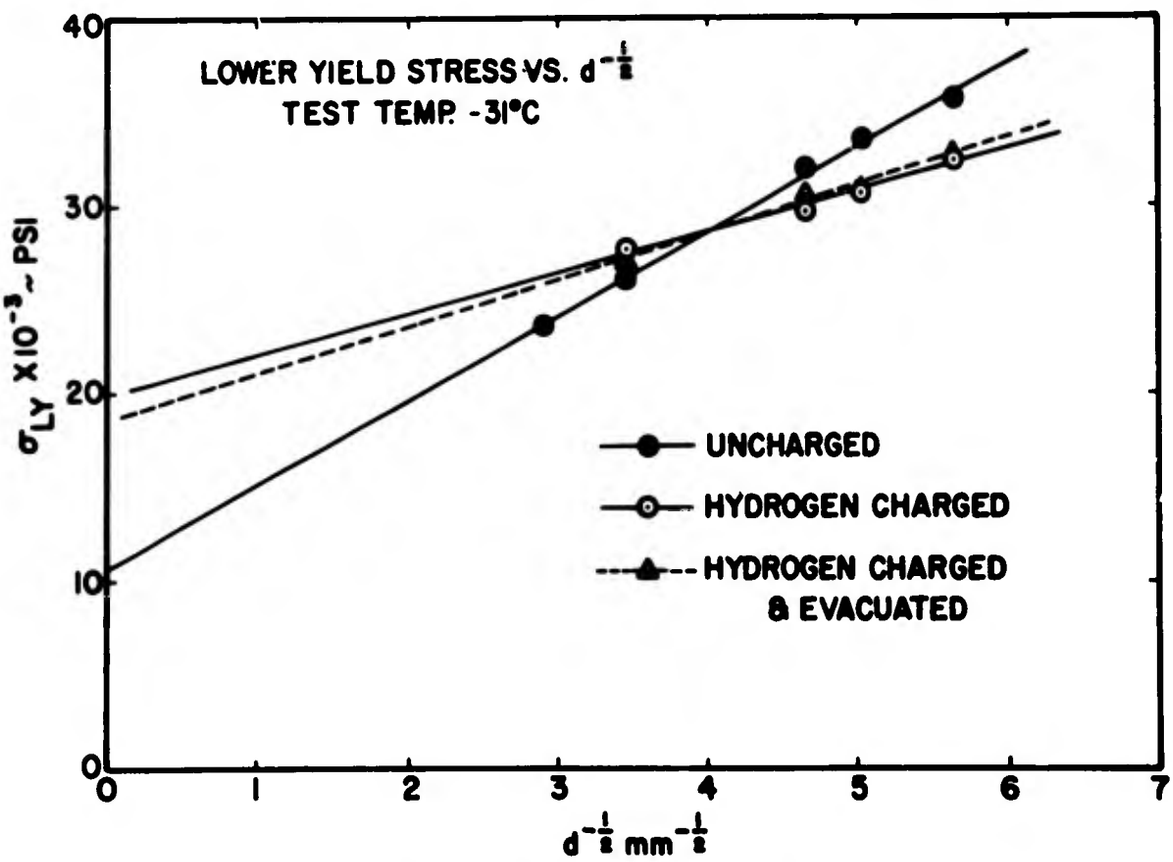


Figure 1. Lower yield stress versus $d^{-\frac{1}{2}}$.

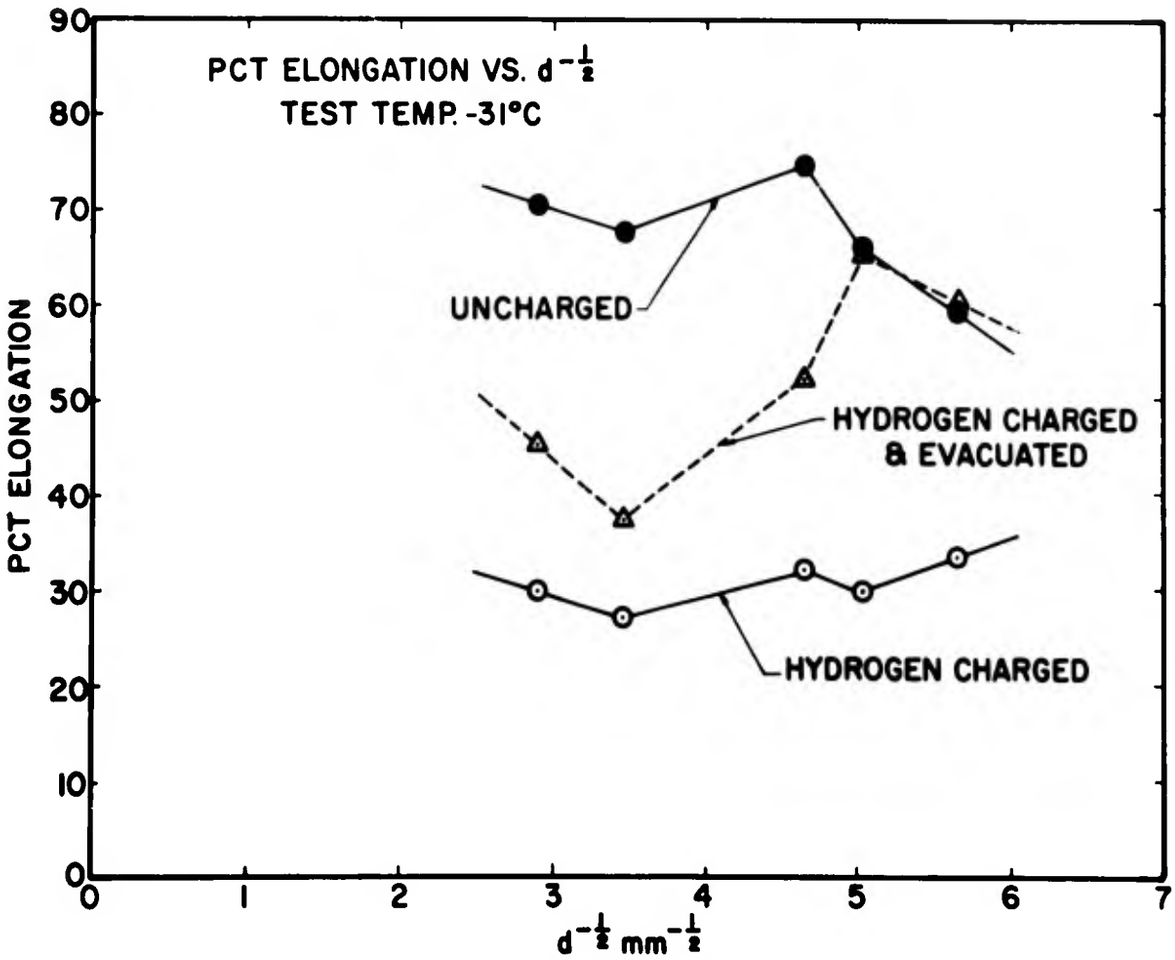


Figure 2. Per-cent elongation versus $d^{-1/2}$.

These results tend to support the gas-pressure theory for slow-strain-rate embrittlement and, in view of the excellent correlation between the delayed-failure behavior of the variety of materials studied and a mechanism based on lattice effects, these results further suggest that the delayed-failure process and the slow-strain-rate embrittlement process are different in kind rather than in degree. This seems reasonable since slow-strain-rate embrittlement results after relatively large amounts of plastic strain, whereas delayed-failure generally does not.

ENHANCED DIFFUSION

materials research

Many of the problems presented to today's materials scientist are the direct result of the high-temperature requirements of modern technology. Ceramic materials, especially the purer two-component metal oxides, are the logical ones to satisfy these requirements. The entire fabrication process of the ceramic materials--including such factors as powder purity, particle size, compaction process, sintering temperature and time -- is secondary only to the material itself in determining the physical properties of the finished piece. In most ceramics the bonding of the grains at high temperature to form a dense, strong compact requires the movement of both the positive and negative ions. Since these species generally move at quite different rates, the entire process will be limited to the rate of the slower species.

The recent literature has presented some

evidence that the movement of this rate-determining ion may be enhanced in the region of material adjacent to grain boundaries. An early diffusion study (Laurent and Bénard) on alkali halides indicated that the rate of the slower-moving species could be increased by orders of magnitude simply by decreasing the particle size to the micron range. Unfortunately, evidence that such enhancement is possible for the high-temperature metal oxides has been limited to a very small number of indirect measurements (Paladino and Coble); e.g., measurements such as creep rate on fine-particle-size compacts, where the rate-determining ion appears to be the normally faster ion, indirectly indicates that the other ion is now moving faster. In addition, no independent experimental work had been presented to substantiate the early work on the alkali halides. Therefore, it was with the dual purpose of independently verifying the diffusion results for the alkali halides, and of substantiating the over-all theory of enhanced diffusion, that Doctors H. C. Graham and N. M. Tallan of ARL undertook the study of the electrical conductivity of sodium chloride as a function of particle size. Since it is well established that material transport in sodium chloride occurs by the movement of the same charged species which are responsible for its electrical conductivity, the establishment of an enhancement in conductivity would verify the diffusivity results.

The positive-ion conductivity (the normally faster moving species) did not vary with a change in the particle size. However, the negative ion showed an increase in its conductivity directly proportional to the decrease in particle size. In addition, for particle sizes in the micron range, the magnitude of the negative-ion conductivity was greater than the positive ion's. Therefore, the results completely supported the diffusion work and the theory of enhanced diffusion in the grain-boundary region.

There is now little doubt that the ion which is normally found to be the slower-moving species can make a major contribution to mass or charge transport in polycrystalline ceramic materials and, in fact, can even become the faster-moving species in ultra-fine grained ceramics. Consequently, the mechanism of the enhanced movement in the grain-boundary region must receive increased study. Without such further clarification of this phenomenon, it may be impossible to make significant progress towards the goal of being able to accurately predict and control essential fabrication processes, and thereby fill the gap in materials for use at high temperatures in oxidizing atmospheres.

mechanics

STABILITY OF UNIFORM ELECTRICAL-CURRENT FIELDS

Magnetofluid-dynamic and electrical devices that use high-temperature gases to conduct current are usually designed on the assumption that their current fields are uniformly distributed over the electrodes. However, the electrical conductivity of a gas increases with temperature, so that a local increase in temperature produces increased ohmic heating, which again increases the gas temperature. Current fields in high-temperature gases may consequently be unstable, which could result in damage or reduced performance.

With this problem in mind, Mr. K. R. Cramer of ARL's Thermomechanics Research Laboratory has conducted an in-house theoretical study on the stability of current field in a nonflowing gas. The results demonstrated that uniform current fields in continuum gases are unstable for small temperature disturbances, and that current filaments will be formed between electrodes. Filament half widths were estimated to be very small and not strongly dependent on their peak temperatures, responding to voltage changes in less than a microsecond. The formation of numerous shorting filaments between adjacent electrodes in magnetohydrodynamic (MHD) Hall devices was suggested as the cause of Hall potential losses.

This research has application in the area of MHD generators, Hall accelerators, and other devices using large electrode surfaces in which local phenomena sometimes cause problems that field equations cannot describe. Cramer's work has indicated controlling parameters and operating ranges, and gives an insight into what might be done to avoid interaction between, and erosion of, electrodes.

RESEARCH IN PLASMA TECHNOLOGY *mechanics*

At present, the only means available for producing continuous plasma streams of very high temperatures and energy densities is the electric-arc discharge. As an electrical "gaseous heating element" through its thermal and magnetic properties, it finds many applications in aerospace systems for re-entry simulation, for space propulsion, and for the generation of high-intensity radiation. The attainable temperature of the column of an arc discharge depends primarily on the rate of heat transfer to its environment, and thus on the mechanism of this heat-transfer process.

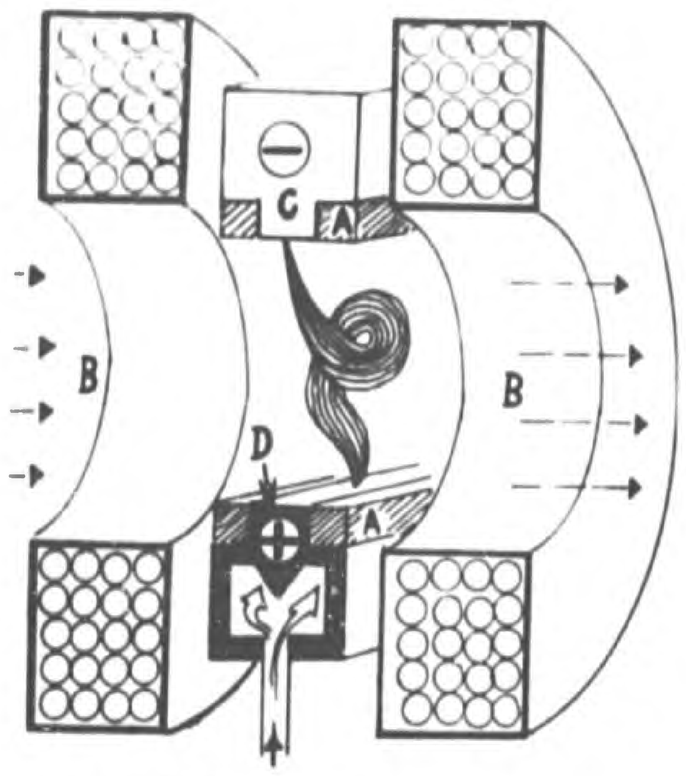
These processes are being studied at the Aerospace Research Laboratories under an integrated in-house and extramural research program, supplemented by thesis studies of students at the Air Force Institute of Technology.

In some design configurations of arc-heating devices, the electric arc is drawn between concentric ring electrodes and moved at high speed over the electrode surface by means of an externally applied magnetic field. This configuration alleviates many of the electrode problems caused by the extremely high heat loads at the electrode surfaces. In such a moving-arc system, the gas to be heated contacts the arc column in a direction normal to its axis. However, little is known of the associated heat-transfer mechanism and the flow around the arc column; correspondingly, it is not possible to assess and to predict the heating potential of arc columns in transverse gas flow, unless details of flow and heat transfer are known.

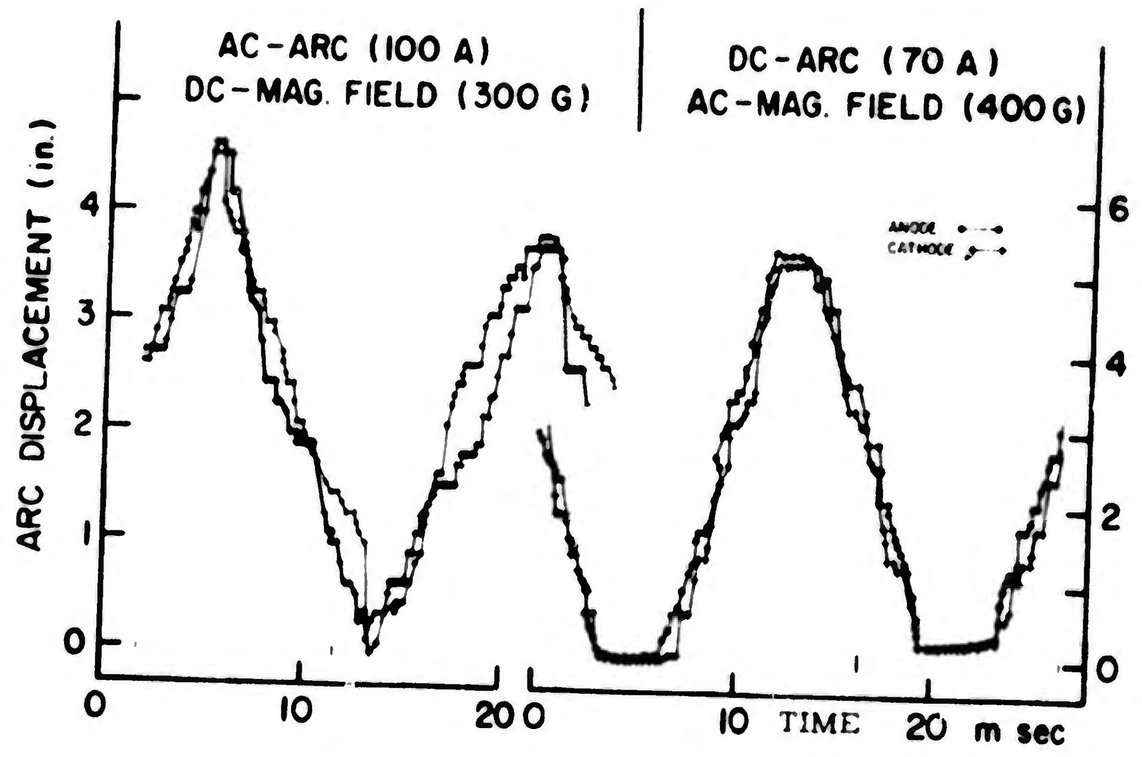
Therefore, for several years, studies of arcs in cross flow have been conducted at ARL. Greer, Eckenroth, James, and Roman have investigated magnetically driven arcs between concentric ring electrodes. Roman has also studied the motion of such arcs along parallel rail electrodes. James, Roman, Schrade, Weichel, and Gianotta have studied arc motion at very low pressures. Most of these studies have yielded information on the arc velocity as a function of arc current, magnetic-field strength, electrode geometry and gas properties. Also, very interesting information was obtained on the shape of the discharge and the motion of the electrode attachment points.

Figure 1 shows a typical sequence of high-speed motion pictures of an arc moving in air of one atmosphere pressure over parallel rail electrodes under the influence of an external transverse magnetic field. From the photographs and the diagram, which indicates the arc spot movement as a function of time, one may observe the following: (a) the arc column appears as an amorphous plasma cloud without apparent structure, its shape varying considerably over the path of travel; (b) the arc attachment points or electrode spots move discontinuously in random "jumps" over the electrode surface. Sometimes they may even move in a backward direction; and sometimes two or more spots seem to exist simultaneously. Although these moving-arc studies have yielded very interesting results, none of them have provided any insight into the mechanism of heat transfer from the arc to the environment. Its aerodynamic properties could be represented by a "drag coefficient"; however, in view of the considerable uncertainties with regard to the definition of a characteristic arc dimension, and specifically with regard to the problem as to whether or not an arc column is transparent to the oncoming gas flow, such drag coefficients will have limited application.

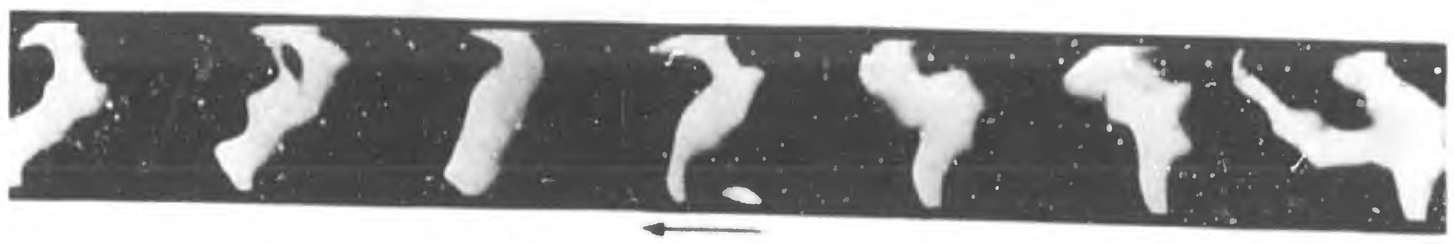
In order to gain a better understanding of the energy-exchange process, a different approach was initiated. Instead of studying



APPARATUS



OSCILLATORY MOTION OF ELECTRODE SPOTS



HIGH-SPEED PHOTOGRAPHS OF ARC MOTION ALONG RAIL ELECTRODES
(26, 000 frames/sec.)

Figure 1. (a) Apparatus; (b) Oscillatory motion of electrode spots; (c) High-speed photographs of arc motion along rail electrodes (26,000 frames/sec).

moving arcs in stagnant gas, stationary arcs in moving-gas streams were investigated. In this case, the Lorentz forces generated by the external magnetic field were adjusted to balance the aerodynamic "drag" of the arc column. This approach yielded better-defined arc columns, and permitted the application of simpler diagnostic techniques. A study of such a magnetically balanced arc in supersonic flow, conducted at the University of Michigan (Bond), has proved the feasibility of stabilizing an arc, even in very-high-flow velocities. Surprisingly, it was found that an arc column drawn between straight rail electrodes aligned parellel to the direction of flow assumes a slanted position, with the slant angle being nearly equal to the Mach angle of the flow.

A subsequent study at ARL by Dr. Ward C. Roman was designed to obtain detailed information on the distribution of the thermal and kinetic energy in the immediate vicinity of the arc column. In this experiment, a spatially well-defined arc column, positioned normal to the flow of a subsonic wind tunnel, was balanced by the Lorentz forces of an adjustable external magnetic field (Figure 2). Through miniaturized total-pressure and enthalpy probes, the velocity and temperature fields beside and behind the arc column were measured for various gas velocities, balancing magnetic-field strengths, and arc current. The following interesting and partly unexpected results were obtained:

(1) the arc column behaved like a solid aerodynamic drag body, impervious to the gas flow.

(2) the shape of the cross section of the discharge changed from an initially circular geometry, for zero gas flow and magnetic field, to a relatively flat, nearly elliptical geometry for finite gas flow and magnetic field. The major axis of the ellipse was always aligned perpendicular to the flow direction; the major-to-minor-axis ratio increased with increasing flow velocity and magnetic-field strength. The calculated drag coefficients, when based on the initial arc diameter,

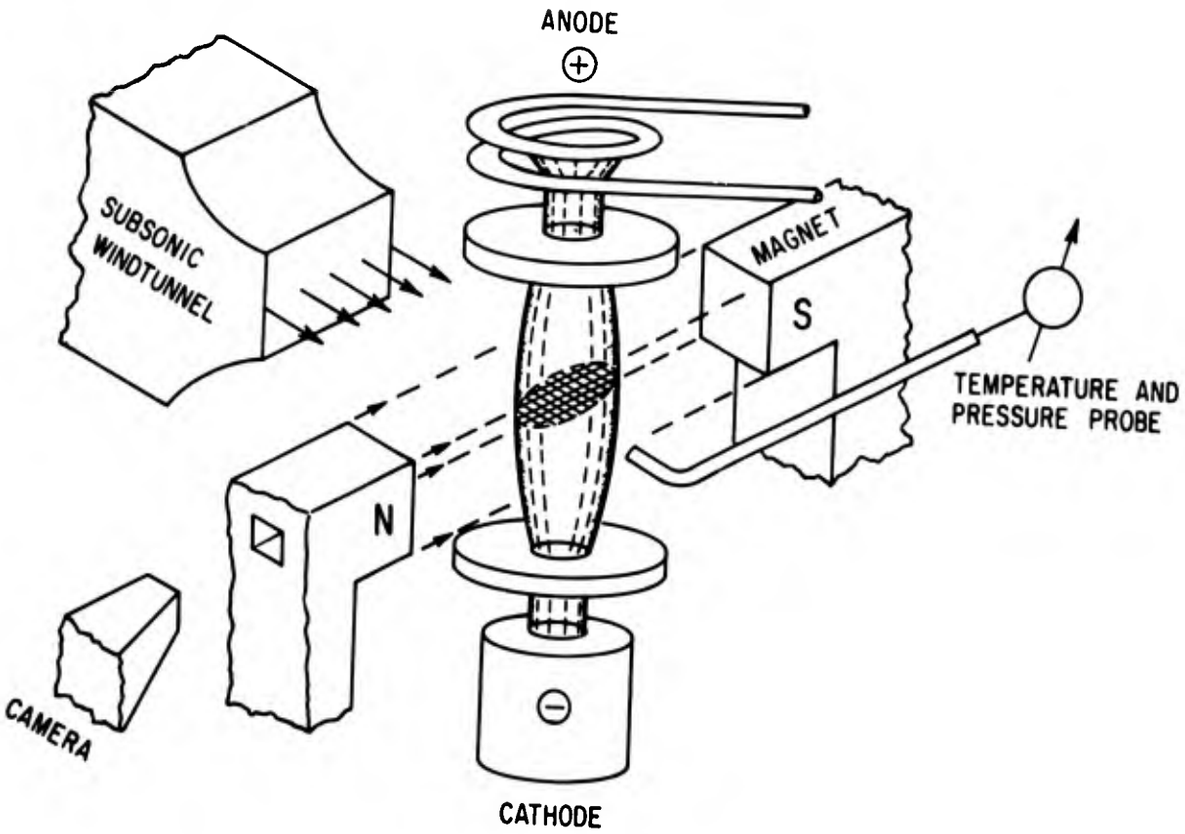


Figure 2. Arc in transverse flow.

appeared unreasonably high; when based on the actual arc dimension, they were in close agreement with those of solid cylinders. Figure 3 shows qualitatively a velocity profile as measured in a plane 1/4 inch behind the arc column. Also shown are some boundaries of the wake as a function of the arc current; and shown for comparison is the wake boundary of a cold solid cylinder of equivalent dimension.

Qualitatively, this arc behavior may be explained by the existence of a dual vortex flow system within the arc column; such a system may be generated by a magnetically induced pumping process as was found and explained under a study of arc retrograde motion by Schrade (see OAR Progress '65, p. 46). Further experiments are being prepared to determine the flow pattern within the column of the arc proper.

This work provides insight into the basic energy-exchange processes between electric-arc columns and gas flow moving transversely to the axis of the discharge; it also gives important information on the motion

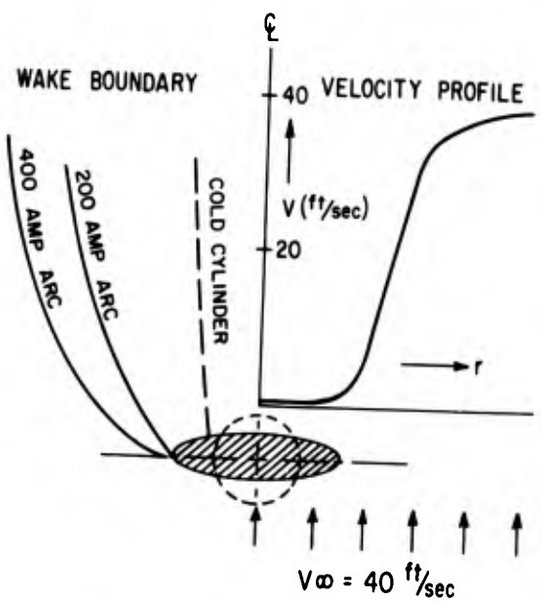


Figure 3. Velocity field behind arc.

of the arc columns and the electrode attachment points under the influence of magnetic fields. It therefore is relevant to many problems of the design and operation of arc heaters operating at elevated pressures, such as are used in advanced re-entry simulation facilities in various laboratories of the Department of Defense and the National Aeronautics and Space Administration.

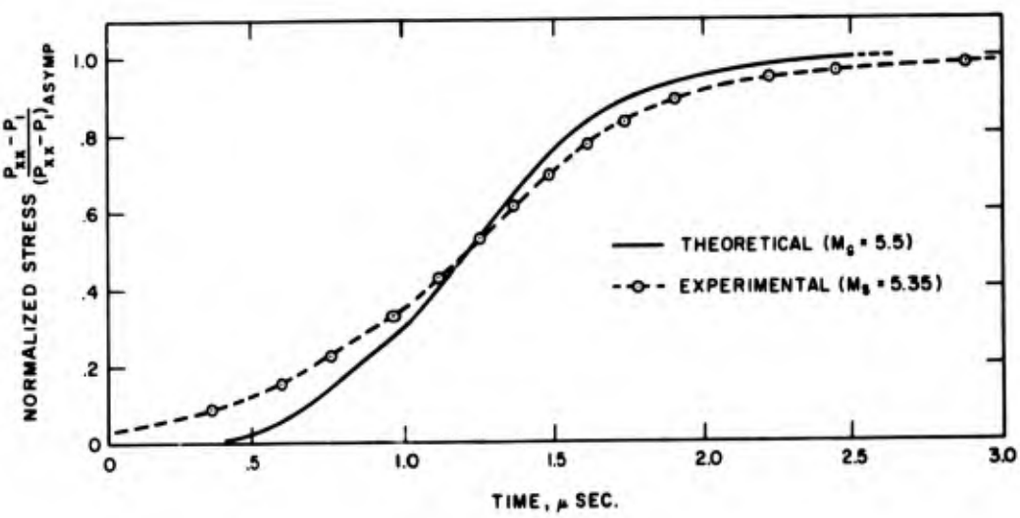
Present efforts at ARL are concerned with extending these investigations to much higher pressure levels ranging as high as 1,000 atm. Studies of the radiative properties and electrode phenomena of high-pressure arc discharges are expected to yield results directly applicable to future high-performance arc heaters and high-intensity radiation sources for re-entry simulation and materials testing.

mechanics

REFLECTION OF A SHOCK WAVE IN A SHOCK TUBE

A strong shock wave is an example of a rarefied flow, in that a gas exhibits its molecular character when it passes through a strong shock. For this reason, strong shock waves can be valuable tools for investigating the validity of the various mathematical models used to approximate real gases in rarefied flows. Accurate experiments on the internal structure of strong shock waves have been made possible by the construction of low-density shock tubes, such as the 17-inch shock tube at FJSRL. The most significant measurements have been made by instrumenting the shock-tube end wall and measuring conditions, such as the normal stress and heat-transfer rate, when the shock wave is reflected from the end wall. These experimental data may be compared with theoretical solutions of the same shock reflection for a critical examination of the mathematical models.

Analysis of the shock-reflection problem for two popular fluid models has been undertaken by Dr. J. S. Petty of ARL. The first model to be studied was the continuum-fluid model as described by the well-known Navier-Stokes equations in which the gas is assumed to be continuous in character, rather than



END-WALL P_{xx} HISTORY; ARGON

Figure 1.
Numerical analysis of the shock-reflection problem for the continuum-fluid model described by the Navier-Stokes equations compared with experimental results.

molecular, and molecular effects, such as slip at solid boundaries, are either suppressed or introduced purely as assumptions. The continuum equations have been solved numerically, using an IBM 7094, and the results have been shown to be qualitatively similar to experimental results obtained at the California Institute of Technology. A sample of these results is shown in Figure 1. Quantitative agreement was not expected since molecular effects, which were known to be physically important, were suppressed in the continuum model.

At present, the numerical solution of a kinetic theoretical model is under way. In this model, the molecular character of the gas is retained, and the results are therefore expected to be more accurate representations of reality.

AERODYNAMIC CONTROL SURFACES FOR VERY-HIGH-SPEED VEHICLES

A study of the effect of aerodynamic control surfaces on hypersonic vehicles has been conducted at ARL by Major John P. Thomas. The investigation encompassed various fin configurations mounted on the same body. Need for this type of work becomes apparent when one realizes that the next generation of re-entry vehicles will be lifting configurations with aerodynamic controls, and that the United States Air Force will be flying aircraft in the same speed range (see drawing, Figure 1) within the near future. Knowledge is required of the changes in flow patterns, pressures, and heating on the vehicle caused by the movement of the control surfaces.

Experimental as well as analytical work has been accomplished in the study. The experimental investigation was conducted in one of ARL's hypersonic wind tunnels, with resulting flow-visualization and pressure measurements. During the analytical portion of the study, prediction of the pressure field on the body was successfully completed. Once the pressure field has been predicted, the skin friction and body heating may be mathematically approximated. With this information, the aerospace designer will have the ability to determine the effect of a moving control surface on a high-speed vehicle. The interrelationship between the flows around the control surface and the body plays an important part in the over-all effect of the control surface. It is not possible to describe one flow without the other because of the intermesh of the flow patterns.

The experimental and analytical investigations are continuing with different aerodynamic configurations applicable to the high-speed flight regime. The shape and degree of leading-edge bluntness of the control surfaces have a marked effect on the final outcome of the flow pattern around the vehicle.

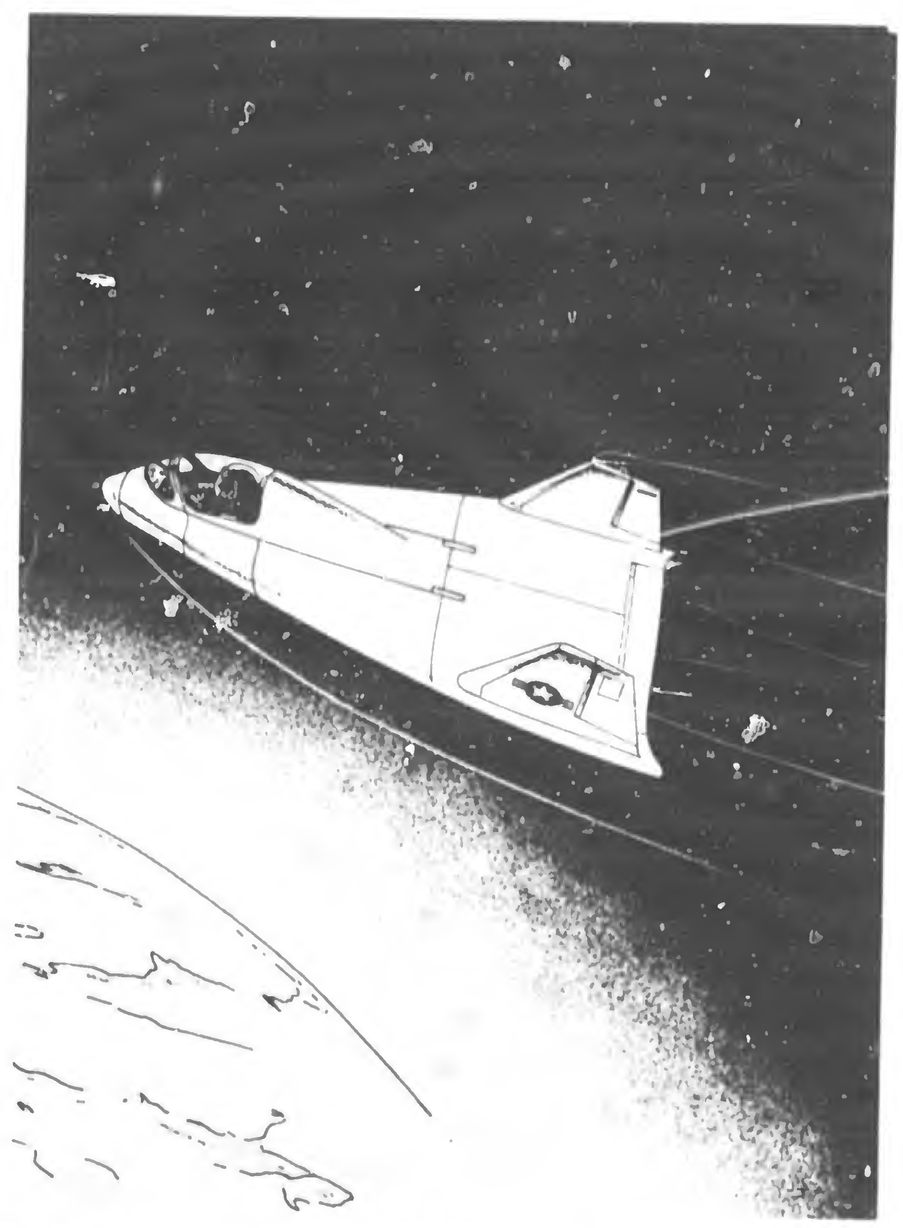


Figure 1. Artist's conception of hypersonic aircraft.

NOSE-BLUNTNESS EFFECTS ON DYNAMIC STABILITY

The delivery of a given pay load to a prescribed location is the final mission objective of all missile systems. The attainment of this objective requires that the system be capable of correcting any deviation from the planned trajectory during all phases of its flight. With particular reference to the vehicle's performance in the atmosphere, completion of the mission demands that the configuration be statically and dynamically stable. At the same time, however, the vehicle must be provided with some means for accommodating the severe aerodynamic heating which it encounters during re-entry. This can be accomplished by several techniques, one of which is blunting the nose of the missile. Although this method alleviates the heating, it sufficiently alters the flow field around the vehicle to create another problem -- the corresponding change in the pressure distribution is destabilizing.

The effect of marked nose bluntness on the stability of slender cones has recently been theoretically studied at ARL by Lt Brian Quinn. The analysis involved perturbing the blast wave-piston analogy enunciated almost 10 years ago by G. G. Chernyi of the Soviet Union. This analogy recognizes the similarity between the hypersonic flow over a blunt cone and the motion of a toroidal slug of gas which is bounded externally by an explosion's shock wave, and internally by a piston which is simultaneously compressing the gas. The analogy is mathematically formalized by means of the equivalence principle, and by equating the energy released by the explosion to the work done by the vehicle's nose drag in moving a unit distance.

By approximating the perturbed quantities with power series, it turns out that the perturbation pressure is the sum of two components -- one which is in phase with the pitching motion of the vehicle, and another which lags this motion by 90 degrees.

An expression for the pitching moment follows directly from the pressure distribution. In the adjoining figure, where η is the ratio of the nose radius to the base radius, and θ is the half angle of the cone, values of the static $C_{m\alpha}$, and dynamic $C_{mq} + C_{m\dot{\alpha}}$, stability derivatives from some recent ARL experiments, are compared with the results of the analysis.

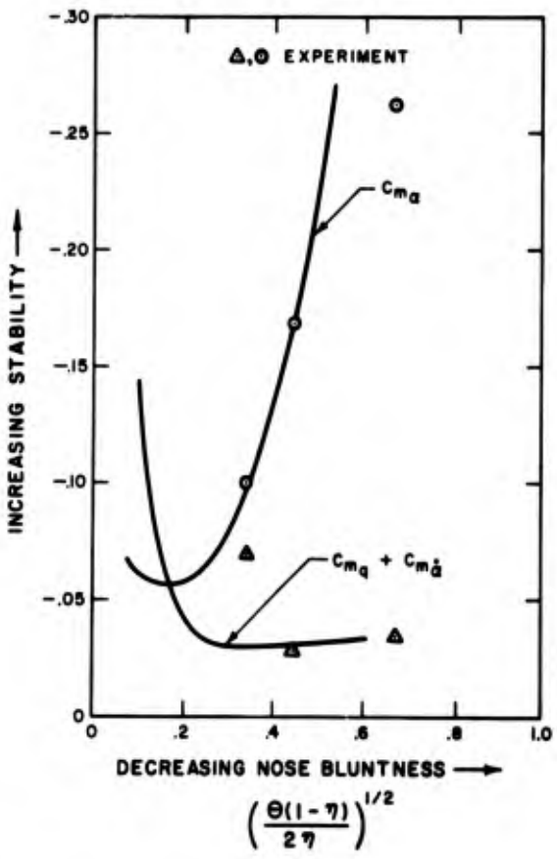


Figure 1. Dynamic-stability coefficient plotted against nose-bluntness ratio.

HYPERVELOCITY LAUNCHING RESEARCH

The ballistic range, because of its ability to accelerate a known aerodynamic shape to an accurately known velocity in a variety of atmospheres and conditions, has been used successfully for many years to investigate hypersonic phenomena. The range can be utilized for hypervelocity-impact research and, as such, has been particularly useful in dealing with meteorite impact and its military counterpart in antimissile defense problems. A very large effort has been expended to increase the velocity capability of these devices. Propellant-driven guns were limited to velocities of the order of 8,000 to 10,000 feet per second. Later, they were superseded by light-gas guns which produced velocities up to 15,000 to 20,000 feet per second. Finally, by multiple-staging, light-gas guns could produce velocities up to about 30,000 feet per second. This performance barrier is unfortunate, since velocities of interest for many space-research problems extend presently to 50,000 to 60,000 feet per second, and the velocities of interest are expected to increase in the foreseeable future.

The problem in extending the velocity limit is that the pressures and temperatures that can be produced and contained in a laboratory apparatus are limited. In 1959, Dr. I. I. Glass, of the Institute for Aerospace Studies, University of Toronto, suggested that this problem could be overcome by using spherical imploding waves instead of the planar waves that are the basis of most of the existing launchers. With partial support from ARL, the Institute designed and built an implosion-driven hypervelocity launcher. The launcher, designed about the concept of using spherical imploding waves, is shown in Figure 1.

The principle of operation of such a launcher can be explained briefly, as follows. The gaseous mixture is ignited at the origin with sufficient violence to generate a detonation wave in the gas. The detonation wave propagates outward spherically and reflects from the surface of the explosive, igniting it instantaneously and uniformly over its entirety, and generating an explosively driven imploding shock wave. This shock wave converges toward the center, increasing in strength as it approaches the origin. On reflection, it leaves a very high-pressure and high-temperature gas which overloads and bursts the diaphragm. The gas acting on the base of the projectile accelerates it along the barrel.

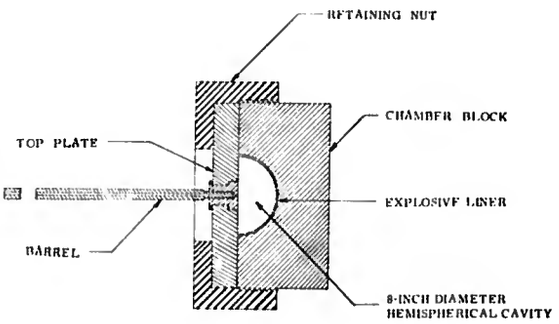


Figure 1. Implosion-driven hypervelocity launcher of the University of Toronto's Institute for Aerospace Studies.

Preliminary experiments with 22-caliber models have demonstrated the feasibility of the imploding spherical-shock-wave principle. Velocities in excess of 7,000 feet per second were obtained. Several experiments, using small amounts of solid explosives in very thin layers, have been run, and velocities of 15,000 feet per second have been obtained. Further runs, using a larger (5/16-inch-diameter) projectile, have produced velocities up to 18,000 feet per second. Extrapolation to much larger models, and to velocities above 50,000 feet per second, is now considered to be well within the realm of current technology. The University of Toronto is continuing this work with the construction of a larger-bore hypervelocity gun, capable of launching 1-inch-diameter aerodynamic models.

AN IN-HOUSE FACILITY FOR SUPERSONIC-COMBUSTION SIMULATION

It is generally recognized that supersonic combustion offers a strong potential as a propulsion mode for ramjet operation at hypersonic flight speeds--resulting in the vehicles now referred to as Scramjets. It is also widely recognized that extensive studies in ground-test facilities are necessary if this new and promising technology is to advance rapidly. Existing test facilities are not capable of providing continuously the very-high-enthalpy test conditions required for complete duplication of the flight environment at the upper Mach numbers of interest. Continuous-type test facilities--those providing seconds as opposed to milliseconds of test time--are required for the investigation of a number of time-dependent aspects of supersonic combustion. In order to provide this type of facility within the present state of the art, it is necessary to consider separate investigations of combustor and inlet problems, and also even then to simulate, rather than fully duplicate, all parameters.

An investigation of the problem of developing a ground-test facility for supersonic-combustion studies was undertaken at the Aerospace Research Laboratories in mid-1965 under the direction of Mr. E.G. Johnson and Dr. R. G. Dunn. The investigation was composed of two separate studies: one to determine what parameters need to be duplicated in the combustion chamber, and the other to determine the feasibility of utilizing the major components of one of ARL's hypersonic wind tunnels for supersonic-combustion investigations.

The study of parameter-duplication requirements resulted in a type of simulation in which the Mach number in the combustor is not an important parameter, as is the case

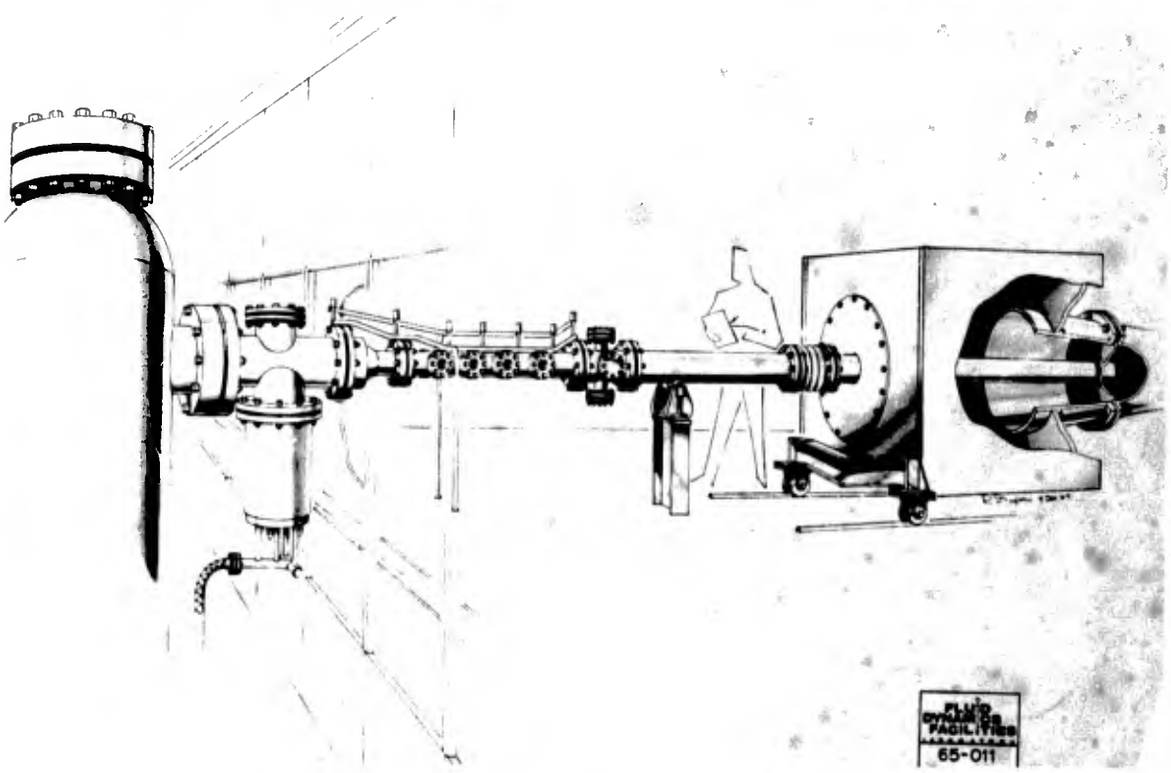


Figure 1. Supersonic-combustion-simulation facility.

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in the usual aerodynamic investigation. In the supersonic-combustion problem as applied to Scramjet, the chemical composition of the flowing medium, the mixing of the streams of fuel and air, the chemical reactions taking place, and the reaction rates involved are the important factors to be considered. Investigation of the chemical aspects (composition, reactions, reaction rates) requires that the laboratory experiments be run under the same static pressure and temperature conditions as in the flight, and also that the residence time in the combustor be the same. The flight parameters not duplicated in the laboratory are the absolute velocities of the fuel and air streams; however, these velocities may be chosen such that the residence time in the laboratory is nearly the same as in flight. In this part of the research, a detailed investigation was made to define the laboratory conditions which would be required for adequate simulation of supersonic combustion for high-Mach-number flight over a wide range of operation.

Once the simulation technique was established, a study was initiated to determine the feasibility of using the major components of an existing facility to form the basic elements of the supersonic-combustion-simulation facility. The 30-inch hypersonic wind tunnel was the most attractive from this point of view, and efforts were directed to the modification of this facility.

Several new components were developed and added to the existing facility. Included in these components were: a hydrogen storage and control system, a hydrogen heater, a hydrogen injector, and a combustion chamber. The facility is primarily designed for using gaseous hydrogen as the fuel, but other fuels can easily be handled.

The present configuration of the facility (Figure 1) allows simulation of the combustor conditions for a vehicle flying at Mach 12, and at an altitude of 140,000 feet. Modification of the hydrogen injector will permit simulation over a wider Mach-number and altitude range.

RESEARCH ON BLUNT-TRAILING-EDGE BLADES FOR SUPERSONIC COMPRESSORS

In some applications, such as small gas turbines, direct-lift engines, and supersonic cruise engines, the use of a supersonic compressor could substantially reduce the cost, complexity, size and weight of the over-all system. The research program on supersonic axial-flow compressors at ARL is focused on the investigation of a particular compressor-blade design philosophy. This is the concept of the blunt-trailing-edge design, an idea which was conceived at ARL and is currently under investigation by ARL researchers. This blading concept is unique in that rotor blade passages of approximately constant area are employed to turn the flow, resulting in a blade having a blunt trailing edge. For this reason, the blade is also simpler to manufacture, and more rugged than typical supersonic blading with sharp trailing edges.

The research program, under the direction of Mr. Elmer Johnson and 1st Lt John Steurer, is divided into three co-ordinated efforts. The results of each, over the past year, have been encouraging. Within ARL, a computer program has been developed by 1st Lt Arthur Wennerstrom and Mr. Stavros Olympios to permit a better understanding of the complicated flow phenomena characteristic of blunt-trailing-edge supersonic-compressor blading. This program is currently being used to optimize blade design and to predict compressor performance. At the Arnold Engineering Development Center, AFSC, the 3,000-horsepower facility built to test the compressor rotors designed by ARL has become operational, and 2 rotor configurations have been successfully tested. Full-stage testing is currently being planned. The 3rd effort, at the von Karman Institute

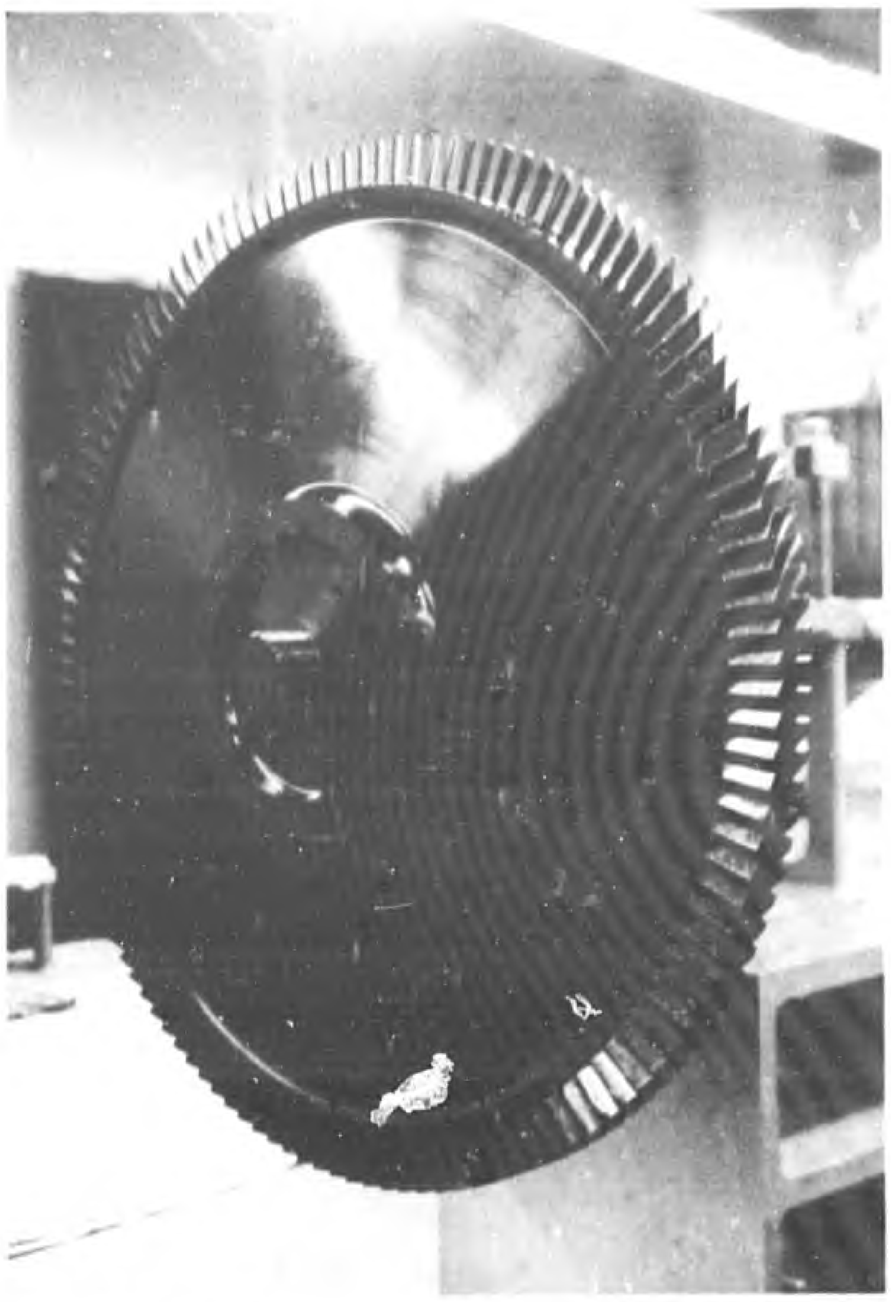

Figure 1. Blunt-trailing-edge supersonic-compressor rotor.

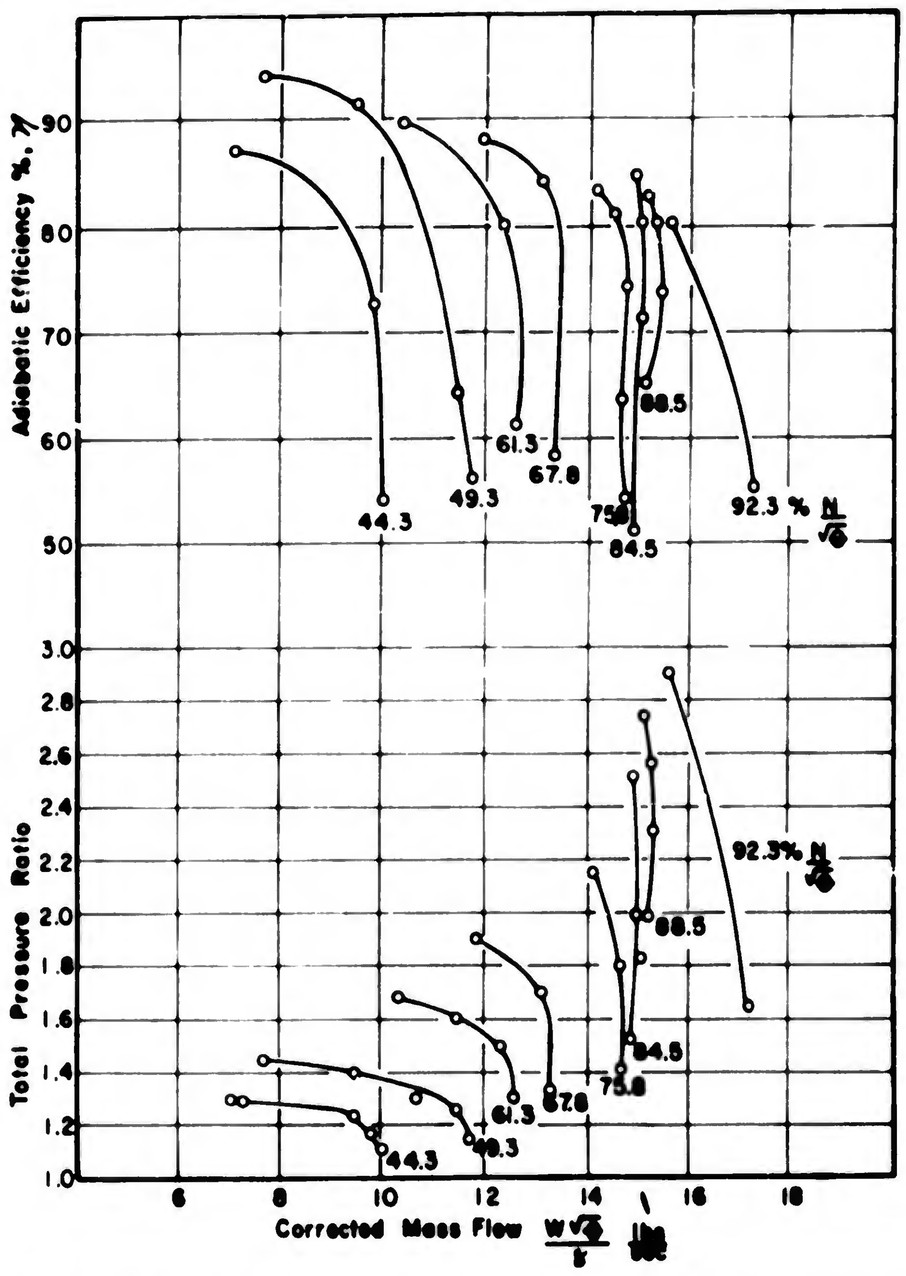

Figure 2. Performance characteristics of rotor tested at von Karman Institute for Fluid Dynamics.

for Fluid Dynamics in Belgium, involves an ARL grant to experimentally study the blunt-trailing-edge concept. The Institute has performed low- and high-speed cascade investigations on both rotor and stator designs. Performance of the 1st rotor was encouraging, having achieved a total pressure ratio of 2.9 at an efficiency of 80% for a relative inlet Mach number of 1.4. A modified version of this rotor is expected to increase the efficiency by another 4 or 5 points. In addition, a blunt-trailing-edge stator has been designed, and compressor stage testing, i.e., testing of rotor plus stator, will begin shortly.

mechanics

RESEARCH USING A LOW-DENSITY SHOCK TUBE

A large multipurpose low-density shock tube has been constructed by the F. J. Seiler Research Laboratory. It is physically located in the Aeronautics Laboratory at the USAF Academy, and is gasdynamically similar to the low-density shock tube in place at the California Institute of Technology.

The tube is 84 feet long with a 17-inch inside diameter. The test-section initial pressure can be varied from 1/2 μ Hg up to atmospheric pressure. Any gas or combination of bottled gases can be used in either the driver or test sections. Mach numbers ranging between 2 and 10 have been attained in argon at various initial pressures. A desired Mach number can be repeatedly attained to within 0.5%. The tube has excellent integrity as a vacuum vessel, with a leak rate of less than .01μ Hg/hour.

The instrument is an extremely versatile device for studies in real gasdynamics (chem-

ical kinetics, shock-associated phenomena, etc.) Primary interest lies in its use for re-entry gasdynamics involving shock-wave structure, and shock-wave chemistry and gas-surface interactions. Current studies involve high-speed, free-molecular-flow instrumentation, rate constants in a chemical kinetic study of dissociating CO_2, and thermal surface accommodation.

One of its values to date has been its use as an instructive tool and research instrument for Air Force Academy cadets. Typical of such uses is that of Cadet C. M. Koliner, class of 1966, who conducted shock-deceleration studies in the tube. Results showed that shock attenuation at the end of the test section is approximately 0.1% per foot, indicating that deceleration of the shock wave is a negligible problem in future re-entry studies.

Many other investigations have been conducted by Academy cadets and faculty, and by FJSRL scientists, and have contributed greatly to the design and construction of the facility.

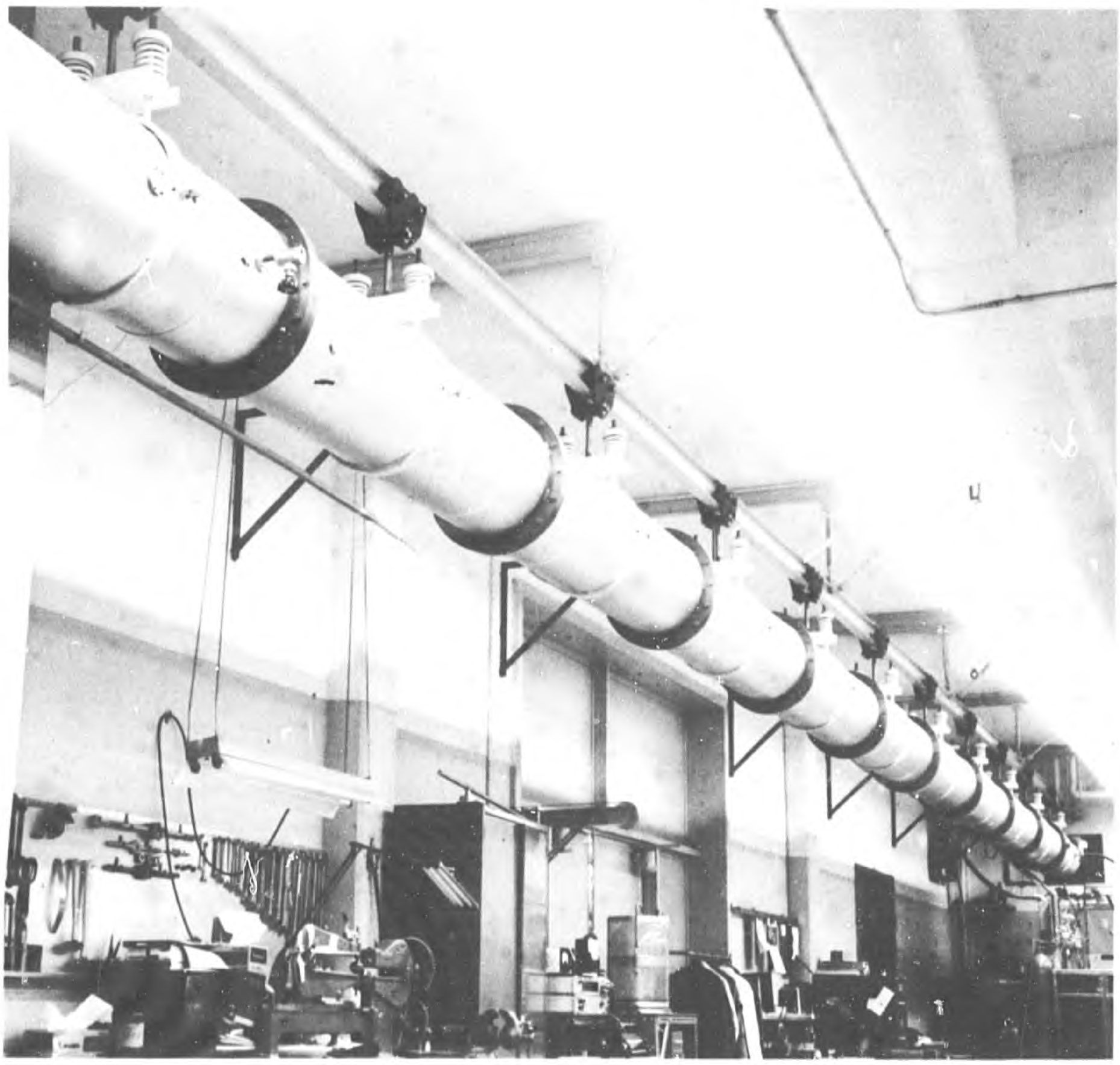

Figure 1. FJSRL low-density shock tube in Aeronautics Laboratory, USAF Academy.

AERODYNAMIC TRANSONIC-FLOW PHENOMENA

The transonic-flow regime, that is, flight close to the speed of sound, has presented investigators and designers with a varied array of perplexing and elusive problems. The theoretical difficulties are centered around the basic complexity (nonlinearity) of the governing equations, and are further clouded by the many different types of airflow near airfoils and slender bodies. Experimental investigators have been hampered by large wind-tunnel interference effects, and by the strong boundary-layer shock-wave interaction effects which play an important role in the determination of the shock position resulting from flight in this regime and the airflow downstream of the shock.

In the past few years, analytical work in the area of transonic flow has been virtually abandoned, perhaps because of the seemingly insurmountable theoretical difficulties and the apparent success of aircraft designers in circumventing the problems associated with transonic flow. Experimental efforts by various researchers have demonstrated, however, the important role of transonic flow in the design of efficient airfoil sections and swept-wing configurations for high-subsonic and supersonic aircraft. An adequate transonic theory would thus lend valuable insight into these problems, and aid in the continuing quest for reduced airplane drag and subsequent higher speeds.

At the Massachusetts Institute of Technology, under the direction of Professor M. T. Landahl, and supported by AFOSR, Dr. P. E. Rubbert has developed a general method of solving nonlinear partial differential equations, and has applied it to the problem of transonic flow. The resulting analysis is general on nonlinear transonic flows. The theory exhibits all the general features commonly observed in transonic flow, and reduces to those of the familiar linear theory outside the transonic regions. In addition, the mathematical technique has since been used successfully by others, and should be very useful to researchers in other areas of fluid mechanics.

The results of this work now provide a tool relevant to the design of aircraft operating in the near-transonic, transonic and low-supersonic regions. Naturally, this concerns the prediction of lift, drag, stability, and maneuverability and control of this class of aircraft.

FLOW OF AN IMPINGING ROTATIONAL JET STREAM

Probably one of the most universal, but as yet least understood, phenomena in the area of fluid or gas dynamics is the behavior of rotational jet flows when these flows undergo a strong interaction, such as impinging on some surface or another jet flow. Some of the most interesting, as well as some of the oldest, unsolved problems in fluid mechanics are of this type. The accurate prediction of the resulting flow field and heat transfer associated with this phenomenon is of upmost importance to allow optimizing portions of fluid-amplification systems. The latter is important to the Air Force for a control system immune to radiation effects, and practically immune to the effects of temperature and corrosion.

The Aeronautical Research Associates of Princeton, Inc., under the direction of Dr. C. duPont Donaldson, and supported by the Mechanics Division of AFOSR, have been investigating such fluid-dynamic problems. Dr. Donaldson's efforts to analyze these flows have been based on the hypothesis that, although fluid viscosity is important in establishing the rotational character of the jet flow, viscous stresses will probably not be very important in the region where the jet

impingement (strong interaction region) is taking place. Using this hypothesis, one of the previously unsolved problems -- the problem of a rotational jet impinging on a flat surface -- was thoroughly analyzed. The complete, exact solution of the equations for a jet having the natural velocity profile impinging on a flat plate was obtained.

These results have already been put to practical use in estimates of heat transfer due to impinging jets, in connection with the Hypervelocity Kill Mechanisms program under the Advanced Research Projects Agency. In addition, the results are applicable to the optimization of particular fluid-amplification circuitry.

DISPERSION-STRENGTHENED METALS AT HIGH TEMPERATURES

mechanics

Because of its practical importance to present and future aviation, nickel, strengthened by dispersed thorium-oxide (thoria) particles, was selected for study by the AFOSR-supported scientist, Professor M. C. Inman, of Pennsylvania State University. Thoria-dispersed nickel -- TD-nickel, for short -- is used in jet engines where its superior temperature resistance permits operation at higher temperatures, with a resulting increase in efficiency. As designers of nuclear-power plants and hypersonic aircraft seek materials of high strength at elevated temperatures, they will turn their attention more and more to dispersion-strengthened alloys like TD-nickel. Dispersion-strengthened alloys have a usable strength of up to 80 to 90 percent, as compared with the 65 to 70-percent limit of the precipitation-strengthened alloys.

The quantitative techniques of electron-transmission microscopy are employed by Professor Inman as the principal investigative technique, with the aim of directly correlating changes in microstructure with corresponding variations in the bulk mechanical properties. Under study at elevated temperatures are such parameters as dispersed-particle size distribution, their state of agglomeration, mean particle spacing, interaction with dislocations in the matrix, and the thermodynamic stabilities of the dispersed particles with respect to the matrix.

The value of the quantitative approach is emphasized by the fact that certain phenomena have been observed in the present study which were not observed in earlier studies of the nickel-thoria system. For example, it appears that the degree of agglomeration of thorium-oxide particles is increased during a single recrystallization process. This new observation concerning dispersed systems could be of practical importance, because any forming method which involves repetitive cycles of working followed by recrystallization may so increase the particle agglomeration that the bulk strength is affected. It was also observed that, after annealing for 200 hours at 1,400°C, the substructure of nickel-thoria exhibits areas where a considerable increase in size of the thorium-oxide particles has occurred. The greatly increased particle size will necessarily lead to a loss of strength. Both these observations will be studied in greater detail under varying conditions.

This study has shown that, if the full value of TD-nickel is to be exploited, a careful quantitative investigation must be made to reveal any processing operations which might lower its strength.

MEASUREMENTS OF DISTRIBUTION FUNCTIONS IN GASES

In fluid mechanics, all macroscopic measurements can be interpreted as the statistical average of multitudinous microscopic interactions. The step by which these microscopic interactions are incorporated into our understanding of the behavior of gases and fluids is through the use of distribution functions. These functions can, in the most elementary way, be said to describe the number of "identical" particles in a given situation which lies within a given incremental velocity vector or incremental energy state. For many problems of current and future interest to the Air Force, a knowledge of these distribution functions in given experimental situations is the sine qua non for correlating theory and experiment, as well as for guiding further theoretical development.

During the last year, several research efforts sponsored by the Mechanics Division, AFOSR, and directed towards obtaining these distribution-function measurements in the laboratory, have progressed to the point where such measurements are now being made routinely.

At the University of Toronto, Dr. J. H. deLeeuw has successfully applied electron-beam techniques to point-by-point measurement of the rotational temperature adjustment of nitrogen in a free jet issuing from an orifice and expanding into a high vacuum. These measurements have clearly shown the "freezing" of the rotational temperature under certain conditions, and have provided the first quantitative confirmation of physical theories relating to the rotational relaxation process in low-density flows. This "freezing" of rotational energy in a wind-tunnel nozzle, for example, has an important influence on the Mach-number distribution downstream of the freezing point, and thus may influence the validity of certain types of data measured in such nozzles.

In another program sponsored by the Mechanics Division to further exploit and develop electron-beam techniques as a diagnostic tool in gas-dynamic research, Dr. E. P. Muntz, of the General Electric Co., has successfully applied the technique to the accurate measurement of the velocity-distribution functions in free-jet expansions of helium and argon, and to the measurement of distribution functions in a normal shock wave. This work has resulted in a very close coupling with investigations of near-wake phenomena, work that is of great importance to the Ballistic Systems Division of AFSC. With the experience gained in the distribution-function measurements, it is now possible to design instrumentation for the measurement of flow velocity in wake flows. In addition, electron-beam diagnostic techniques also have clear application to space-vehicle control-jet investigations, as well as to studies of rocket plumes at high altitudes.

The electron beam has also been applied to the measurement of energy transfer in gas-solid interactions, through the determination of the reflected-particle energy-distribution functions by Dr. G. Patterson and his group at the University of Toronto. Gas molecules from a surrounding gas in thermal equilibrium and at rest are incident on a cooled metal disc. Under conditions of free-molecule flow, the incident molecules are not disturbed by the cooler reflected molecules. A high-energy electron beam is passed through the gas in front of the target disc and parallel to it, exciting the gas to electroluminescence. The rotational energy distribution and number density of the molecules are then determined from a spectrographic analysis of the

light emitted by the gas. Experimental results show the measurements (which can be interpreted to obtain values of energy accommodation coefficients, both for the translational and rotational degrees of freedom of a gas) to be practical, although a high degree of accuracy in the measured quantities is required.

As part of another effort to experimentally determine the energy exchange between gases and surfaces, Dr. L. Trilling and his group at MIT have developed a molecular-velocity spectrometer with a multichannel integrator for use in time of flight measurements, thus complementing the electron-beam measurements. This multichannel system allows nearly simultaneous measurement of the entire time of flight spectrum, increases signal-to-noise ratio over a single channel, and introduces welcome flexibility into the operations of the systems. Several effusive gas sources were constructed and tested with this device. An unexpected deficiency in the low-velocity portion of the velocity spectrum was found. This deficiency persisted even up to Knudsen numbers (computed as the ratio of the mean free path inside the oven to orifice diameter) above 20. It was also noted that very small quantities of gaseous contaminants (e.g., water and N_2) in the inert gas used for calibration alter the velocity distribution appreciably.

Thus, as can be seen, we are now approaching the capability of "Maxwell's Demon," who could follow the trajectory of each particle in nature's game of molecular billiards. The continued exploitation of these techniques should not only enrich the experimental arsenal, but should also provide a powerful propelling force for accelerating our understanding of fluid-dynamical phenomena.

SHAKING A ROCKET TO DEATH *energy conversion*

The occurrence of destructive combustion-pressure oscillations is frequently responsible for the failure of a rocket system through burnout or physical rupture of the combustion chamber wall or other parts of the rocket engine. This is due to the excessively high temperatures, pressures and rates of heat transfer to the injector face and walls of the thrust chamber and nozzle which accompany this phenomenon. In addition, even if complete destruction of the rocket does not occur, combustion instability can play havoc with sensitive control and servo systems which are not designed to accommodate the violent mechanical vibrations which also occur.

In order to improve understanding of the fundamental processes of combustion instability, to provide realistic criteria for a priori design of new rocket motors, and to eliminate, as much as possible, the expensive cut-and-try methods frequently employed in rocket development, AFOSR has supported for a number of years research efforts in various aspects of the complex phenomenon of unstable rocket combustion. One important phase involves the investigation of various mechanisms which can act to initiate or trigger and sustain rocket combustion instability, with the express purpose of obtaining better fundamental understanding of this phenomenon.

Towards this end, under AFOSR sponsorship, a small group of scientists headed by Professor Percival D. McCormack, formerly at Trinity College, Dublin, Ireland and now at the Thayer School of Engineering Sciences, Dartmouth College, has been carrying out a comprehensive investigation (2, 3) of the effect of severe mechanical vibration of the injector plate on liquid- and gas-fuel jets. Their main interest in this investigation lies in the possibility of this mechanism's acting as an initiating mechanism for high-frequency combustion instability in the rocket engine -- either on the ground test stand, or in flight.

The sensitivity of jets, gas or liquid, to mechanical vibration of the orifice is an area to which very little attention has been given since the days of Lord Rayleigh around the end of the last century. This is surprising in view of the prevalence of vibration in mechanical systems, and in view of the possible

effect on combustion or fluid jet amplifier operation.

In the case of a laminar liquid jet, Professor McCormack found that transverse vibration of the orifice (circular) can drive the capillary-type instability, first analyzed by Rayleigh (4) and then by Weber (5). This is provided the wave length of the disturbance on the jet is less than the circumference of the jet. In fact, Professor McCormack was able, for the first time, to check the validity of the Rayleigh-Weber theory. Within the context of first-order disturbance amplitude, he found that the theory accurately described this type of instability.

The phenomenon of plate or disc formation on a mercury jet had been produced by J. Hartman in Denmark around 1933. He modulated the jet velocity electromagnetically, the ensuing liquid "bunching" producing remarkable discs. By applying vibration with extremely high "g" values (over 200), Professor McCormack was able to produce similar disc formation on laminar liquid jets. The discs were not as large as those obtained by Hartman, but were very pronounced, and suffered by being subjected to atmospheric shattering and bending of the liquid around the edges of the discs. The only explanation for this phenomenon is that the vibration was producing modulation of the jet velocity at the injector. This mechanism at low "g" values acts as a trigger for the capillary-type instability, satisfying the rationally symmetric criterion laid down by Rayleigh.

In the case of a high-velocity atomized jet, Professor McCormack and his colleagues have shown that, while the capillary-type instability has no meaning in this context, high "g" vibration still induces velocity modulation, and the mass concentration in the spray varies periodically at the applied vibration frequency.

Work on gas jets has revealed an interesting analogy with liquid jets. With low-vibration acceleration values, provided the frequency is correct, vortex shedding can be driven. At high-acceleration values, vortex shedding can be driven at any frequency. In either case, the result is a considerably augmented rate of mixing. A fluid-jet classical closed solution for the case of mixing in the presence of a periodic source of vorticity at the orifice has been obtained, and will be published shortly. Besides its direct significance in the field of combustion, considerable light can be thrown on the transition to turbulence from laminar flow by a thorough exploitation of this phenomenon.

The implications of Professor McCormack's research in the combustion instability area has already turned out to be quite significant. The results obtained recently enabled one of the prominent rocket engine manufacturers to quickly diagnose and eliminate an unanticipated instability during the development of one of the Lunar-Excursion-Modules engines.

energy conversion

HETEROGENEOUS CHEMICAL KINETICS IN FLOWING SYSTEMS

The most accepted way of trying to understand some of the complex phenomena encountered in the real world--indeed, the essence of most basic research in engineering sciences--is to divide the problem into a set of simpler questions. These will hopefully yield meaningful, quantitative experimental results when studied separately, and a satisfactory rationale when finally brought back together again. Until recently, however, attempts to measure heterogeneous chemical kinetics as a separate part of the energetic interaction of fluids with surfaces have not been very successful. The rates and activation energies of such reactions are in most cases only meaningful if made in flowing systems as opposed to static ones--and at once the measurements are no longer separated from the fluid-dynamic variables. This is true not only for the highly important regimes of temperature and pressure associated with re-entry ablation, hybrid com-

bustion, and rocket-nozzle erosion, but also for the very different region of interest of an electrode interacting with a flowing or stirred liquid electrolyte.

Now, however, there are available the mathematical tools for solving much of this problem, largely as a result of the intense theoretical attack by Dr. Daniel E. Rosner of AeroChem Laboratories, under AFOSR sponsorship for the past several years. One of the obviously important processes which can "falsify" kinetics is that of diffusion. A generalized curve for a first-order surface reaction would be expected to follow the diagonal line shown in Figure 1. There exists

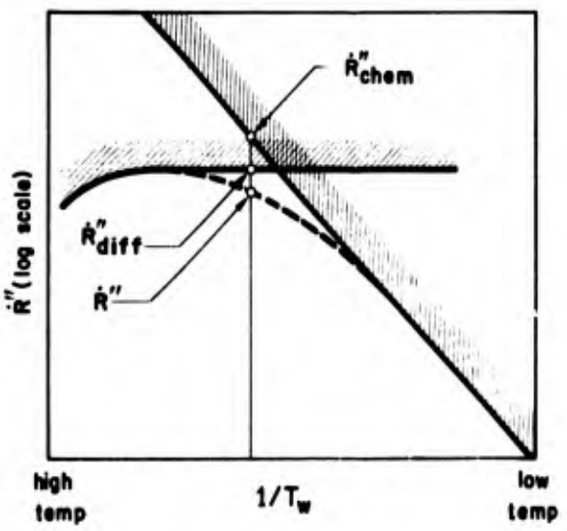

Figure 1. Transition from reaction-rate control to diffusion control on the Arrhenius plane.

some temperature for almost every such reaction, whether the surface is a reactant or a catalyst, at which the apparent rate becomes invariant with temperature (horizontal line in Figure 1); and there is consequently a range over which both diffusion and reaction rate are important. It is this region which Dr. Rosner has successfully treated in a number of theoretical papers in the past year or two. The main conclusions of this, and more recent work, on turbulent boundary layers, on heat transfer along the surface caused by exothermic (or endothermic) reactions, on net mass transfer from the surface, on the effects of various geometries of surfaces, and on the treatment of reactions which are other than first order, are ably summarized in an invited paper for the Eleventh Combustion Symposium (1).

In striking support of this theoretical work, and of immediate interest to rocket and vehicle designers, are the experimental data Dr. Rosner has been publishing on the interaction of atomic species with hot metal surfaces to form volatile oxidation products. True reaction rates of such dissociated gases as O, Cl and OH with graphite, boron, molybdenum, tungsten and other important surfaces have been, or will be, obtained in his laboratory by application of his theoretical conclusions to his raw data. (2, 3, 4, 5) A striking example of the new results, not previously considered by design and test engineers, is the comparison of the true rates of reaction of Cl and Cl_2 with molybdenum shown in Figure 2.

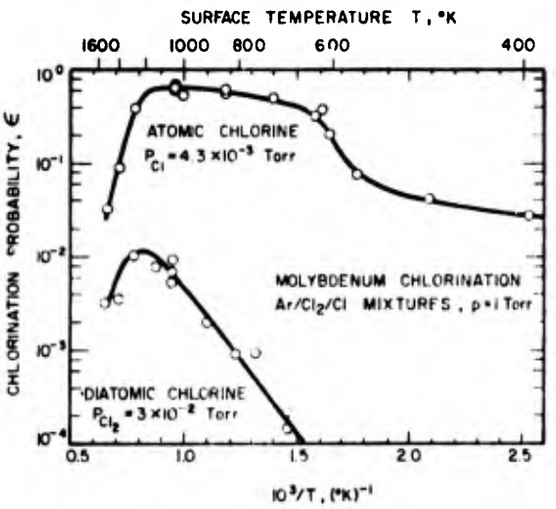

Figure 2. Chlorination probabilities for the attack of molybdenum by atomic and diatomic chlorine.

Thus, Dr. Rosner's two lines of attack reinforce each other; they have already found extensive application in the interpretation of arc-tunnel and combustion-torch test data, in the design (and redesign) of advanced heat shields, in the interpretation of kinetic data, and in the design of probing instrumentation for gaseous reactors. Moreover, it is now possible to predict, in quantitative fashion, the ablative behavior of nozzle inserts and nose cones, given certain materials of construction, the geometry, the gaseous environment, and the flow conditions.

PARTICLE LOSSES IN A SIMULATED CONTROLLED THERMONUCLEAR-REACTOR PLASMA

It has been said (3) that the ultimate propulsion system for solar aviation will be the thermonuclear engine. During the last decade considerable effort has been spent toward the utilization of controlled thermonuclear reactions for power generation and propulsion. Among the numerous difficulties associated with this technological problem is the stable confinement of the working medium, namely, the high-temperature plasma (on the order of 100 million degrees Kelvin).

In the past Aerodynamics, and the more general field of Fluid Dynamics, have exploited the so-called similarity methods (4) which have employed a rather primitive and simplified model to stimulate the zero-order effects characteristic of a very complicated construction. According to this idea of simulation, wind tunnels, water channels, water tables and other simulation equipment were constructed, and experiments were performed on models. The results represented the zero-order-effects behavior of the prototypes.

As experiments with high-temperature plasmas are extremely difficult, the similarity method of approach was used by Dr. Warren McBee of the Sperry Rand Corporation under support of the Propulsion Division of AFOSR. The principle of similarity teaches that phenomena essential to the understanding of stable plasma confinement, under conditions corresponding to full-scale controlled thermonuclear reactors, need not be studied exclusively in hot plasmas; in fact, they may be studied with equal validity (and often with greater ease) in any working medium where the same basic similarity (scaling) laws apply.

Examination of the medium characteristics of a CTR (controlled-thermonuclear-reactor) plasma yielded three important criteria which should be incorporated in the scaling laws. These are:

a. Collision-free plasma, i.e., the particles make many circuits of the trapping field line per mean collision time.

b. The plasma dimensions should be large compared to the Debye radius.

c. The plasma should be in the finite Larmor orbit regime, i.e., the Larmor radius should be of the same order of magnitude as the boundary-layer thickness between the plasma and the magnetic field.

Dr. McBee calculated the microscopic plasma parameters of a typical CTR plasma and those of a cold plasma as found in the TOPSY (Thermally Operated Plasma System).

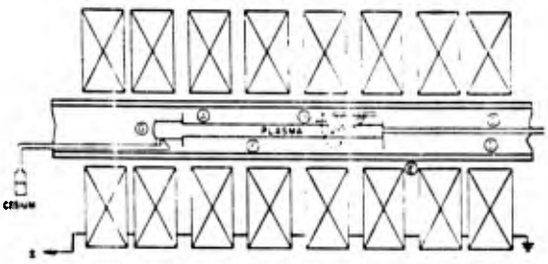

Figure 1. Schematic diagram of the TOPSY thermally generated cesium plasma device. The circled key letters denote (A) the 2.54-cm aperture plate; (B) the seven-probe Langmuir probe array, which is movable axially and in rotation; (C) the axially movable cold end-plate mechanism; (D) the vacuum vessel wall; (E) the magnet coils; (F) the cesium atomic-beam collimator, which produces a 360-degree azimuthally symmetric beam; and (G) the tungsten ionizer hot plate, which is heated by electron bombardment from a filament behind the plate.

He concluded that the positive-ion fluid component in a "cold" alkali-metal vapor reproduces the appropriate scaling laws of electrons in "hot" plasmas corresponding to the CTR conditions. Figure 1 illustrates the TOPSY device.

The simulant plasma in the TOPSY is generated by contact ionization of alkali-metal vapor impinging upon a refractory metal surface. The required simulation is attained through an interchange in the conventional roles of electrons and ions. In order to avoid the macroscopic (hydromagnetic) instabilities, a "minimum B" magnetic configuration is used, i.e., a magnetic field increasing from the center outward.

Initial experimental results of the TOPSY plasma in a uniform magnetic field exhibit the anomalously high plasma loss rates typical of CTR. These loss rates are orders of magnitude higher than the predictions of collisional resistive (laminar) diffusion theory, and agree well with the Böhm (turbulent) diffusion rates. This is clearly shown in Figure 2.

The addition of a transverse (quadrupole-cusped, "minimum B") field appears to reduce the plasma loss rate significantly; however, this is by no means a general effect, and the minimum loss rates are still very large compared with the predictions of collisional diffusion theory.

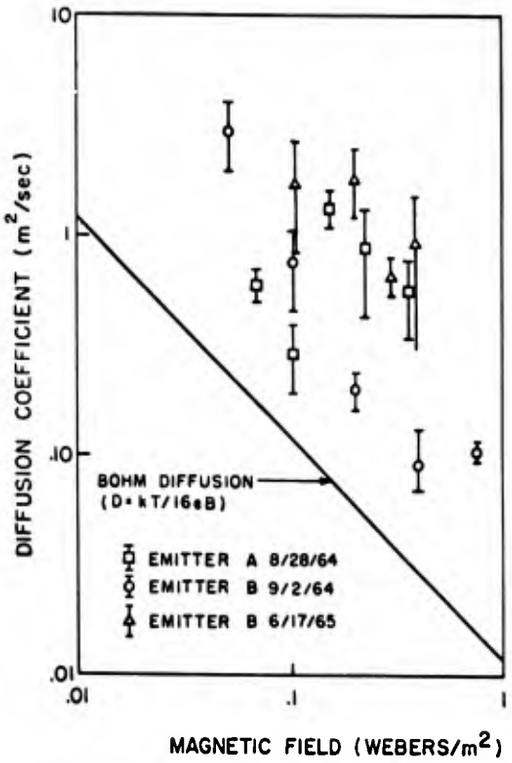

Figure 2. Measurements of the average radial diffusion coefficient in the TOPSY plasma.

atmospheric sciences

MODELS OF THE FORMATION AND DECAY OF THE IONOSPHERE

In studies of the mechanisms responsible for the formation of the ionized regions of the atmosphere (see Figure 1), one of the problems encountered is the solution of a set of differential equations describing the time dependence of the number density of the chemical species present. The solution becomes difficult when more than three constituents and a wide variety of source functions and initial conditions have to be considered.

The need for an effective computer technique became apparent through the DASA nuclear-weapons-effects program when a capability of predicting ionization decay under highly disturbed conditions became necessary. A number of recognized experts have tried to solve the problem on large digital

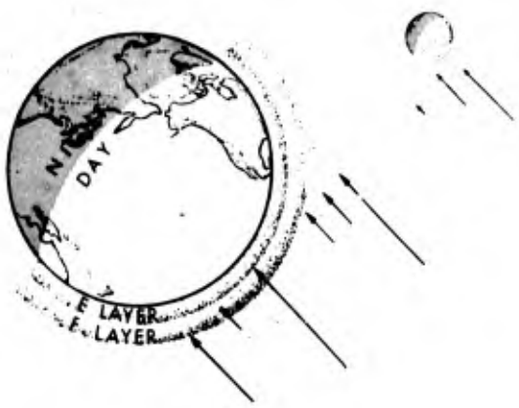

Figure 1. Effect of incoming solar radiation on ionospheric electron-density buildup and decay.

computers, but have not succeeded in producing an economical solution. T. J. Keneshea of AFCRL successfully developed a computer technique for an arbitrary number of species as variables. This solution, published in two AFCRL reports, immediately attracted the attention of the professional community working in this field. The computer program is now used at the Air Force Weapons Laboratory, the National Bureau of Standards, the Lockheed Space and Missile Division, and the General Electric Company.

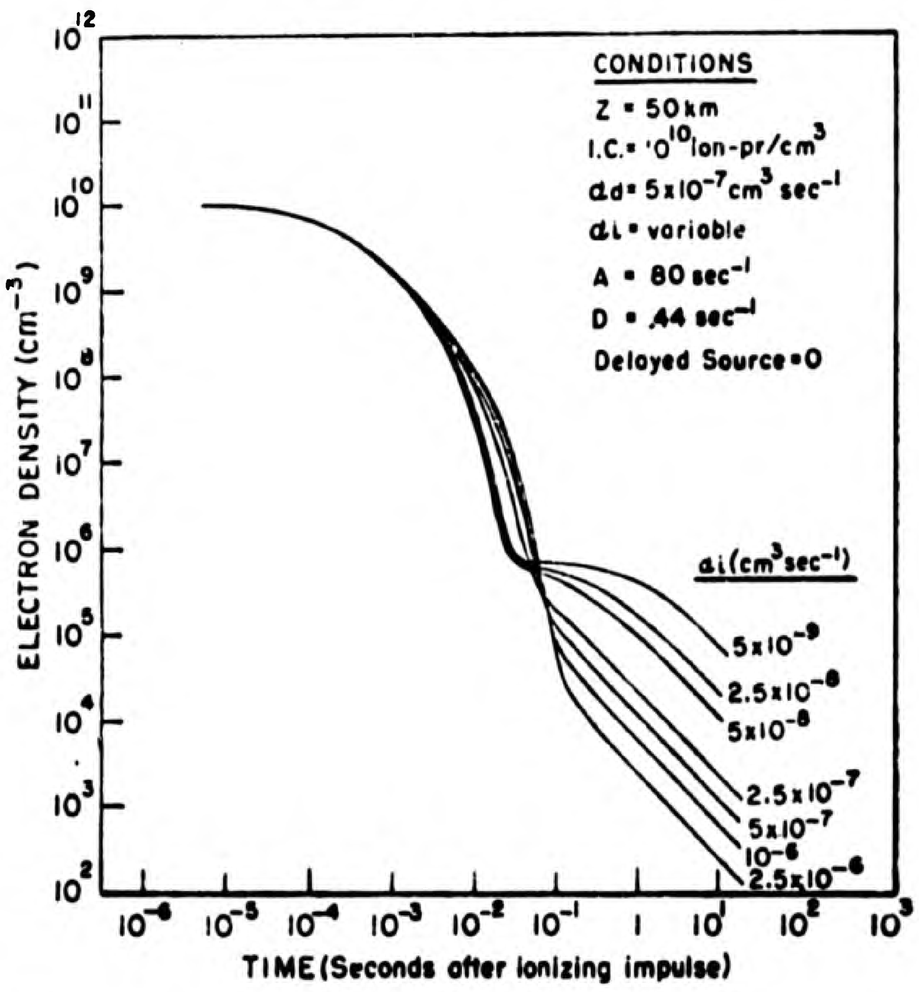

Figure 2. Deionization of the D region at 50 km following an intense initial impulse of ionization. Electron density plotted against time, log-log scale.

Figure 2 illustrates an application of Keneshea's program for 15 atmospheric species. The figure is a log-log plot of electron density vs. time representing deionization of the D region at 50 km following an intense initial impulse of ionization. The variable parameter in the computation is the effective mutual neutralization rate coefficient α_i. This quantity is the ionization-loss controlling process at low altitudes. Keneshea applied his technique to the case of a solar eclipse. He compared theoretical results with experimental data measured with rockets at Fort Churchill during the eclipse of 1963 (July 20), and presented the material at the Spring 1965 International Scientific Radio Union (URSI) meeting.

The necessary input for Keneshea's program is accurate values for the various reactions involved. In a parallel research effort at AFCRL, J. Paulson and his associates are measuring as many reaction rates as possible. One of these is the rate of the process $O^+ + N_2 \rightarrow NO^+ + N$, which is probably the rate-determining step in the decay of the

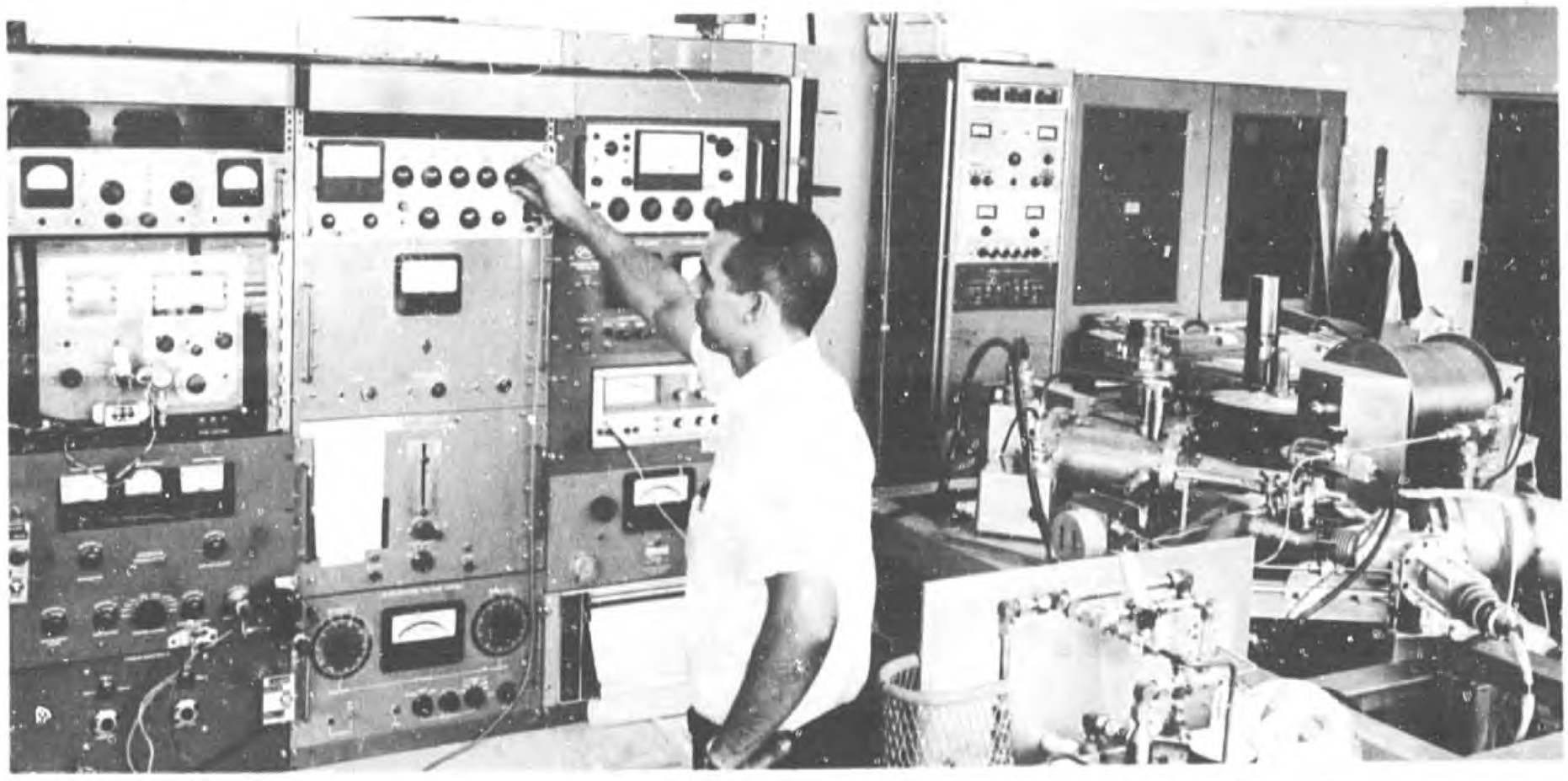

Figure 3. Mass spectrometer used to measure the currents of the reactant and product ions as a function of the kinetic energy of the reactant ions.

nighttime F-region electron density, and is also an important process in the lower ionosphere. The experiments were performed using a mass spectrometer to measure the currents of the reactant and product ions as a function of the kinetic energy of the reactant ions over the energy range 0.16 eV to 20 eV. The equipment used can be seen in Figure 3. The reaction cross section was found to increase rapidly with increasing energy up to about 6 eV, and then to fall off at higher energies. Extrapolation of the data from the lowest energy used (0.16 eV) to thermal (0.04 ev) gives a value of 4×10^{-12} cm^3 mol^{-1} sec^{-1} for the rate constant at thermal energy. These results fill in the gap between the results of thermal-energy experiments and those obtained with beam techniques.

The results of the foregoing research are of critical importance to the Air Force because they can be applied to the development of models of radar and radio blackout following high-altitude nuclear detonations. They are important to the Air Force in any radio-communications problems involving reflection from the ionosphere, or interruptions caused by heavy absorption in the lower ionosphere.

astronomy and astrophysics

COSMIC-RAY TRAJECTORIES

Cosmic rays--atomic nuclei, primarily hydrogen--approach the earth from all directions. When these particles encounter the earth's magnetic field, their trajectories are altered. Some, in fact, pursue an erratic course for several orbits around the earth. Just what trajectory the particle will follow depends on many things--particle momentum, charge, direction of approach to the magnetosphere, and the magnetic-field strength and configuration. The resultant trajectories are so complicated that predicting them is a mathematical problem of some magnitude.

Until recently, only approximate solutions to this problem were available, since each trajectory calculation involves several thousand iterative steps to reach a solution. This problem has become tractable. For the past two years, M. A. Shea and D. F. Smart of AFCRL, and K. G. McCracken of the Graduate Research Center of the Southwest in Dallas, Texas, using computers, have plotted trajectories of cosmic rays in the geomagnetic field. Their calculated values have a much greater consistency with the results of observational cosmic-day data than previous values. Already, scientists from a number of countries, including Australia, England, Canada, Argentina and South Africa, have successfully applied these new values in analyzing cosmic-ray data.

The results of this intensive research are contained in a recent AFCRL report, "A Study of Vertically Incident Cosmic-Ray Trajectories Using Sixth Degree Simulations of the Geomagnetic Field" (AFCRL-65-705). This 350-page report consists largely of computer-generated tables of the trajectories of particles with different momentum and charge at more than 130 locations around the world. The results are the most accurate and complete determinations of cosmic-ray trajectories made to date.

In considering the trajectory of a given particle, it is convenient to consider momentum and charge as a single quantity. This quantity is called the particle's "rigidity," and is the ratio of momentum per unit charge. All particles having the same rigidity, whether an individual proton or a heavy nucleus, will follow the same path through a magnetic field if they enter the field at the same place and from the same direction. The AFCRL report deals with vertical "cutoff rigidities," which are defined as the lowest rigidities particles may possess and still arrive at specific points on the earth's surface from the vertical direction. The three investigators have made a significant refinement to this definition which makes it possible to calculate the effects of the geomagnetic field more accurately. This new definition is called an "effective cutoff rigidity." At the magnetic equator, where the particle must perpendicularly traverse the geomagnetic field, the "effective vertical cutoff

rigidity" is more than 15 billion electron volts (bev), while at the magnetic poles, where the particles are essentially parallel to the field lines, it is theoretically zero.

From this, one would expect to observe (by detecting a cascade of secondaries at the earth's surface) a minimum cosmic-ray intensity at the magnetic equator, and a maximum intensity at the geomagnetic poles. This minimum is, in fact, observed at the magnetic equator; but the maximum intensity is not correspondingly observed at the geomagnetic poles. Actually, there is no localized area of maximum intensity at either pole. The maximum is rather uniformly distributed throughout the entire regions above 55 degrees geomagnetic latitude.

However, if the earth had no atmosphere, or if our observations were made well above the atmosphere, cosmic-ray maxima would be found near the geomagnetic poles, as expected. Why, then, do we not observe these conditions on the ground? It has to do with the particle's cutoff rigidity, which can be thought of as a kind of threshold energy. All particles above approximately one bev are able to penetrate the earth's magnetic field in all regions above approximately 55 degrees geomagnetic latitude. Particles with rigidities lower than 1 bev are not likely to create cascades of secondaries in the earth's atmosphere which are still detectable at ground level. This applies whether they enter at 55 degrees or at 90 degrees geomagnetic latitude, or at any point between.

Because cosmic-ray trajectories are directly influenced by the configuration of the magnetic field, which varies diurnally, seasonally, and with solar-cycle variations, it is possible to derive information on the changing magnetic field by observing cosmic-ray events. Also, because the calculations of cosmic-ray rigidities are equally valid for solar protons, the calculation techniques developed under this study can be used to evaluate the trajectories of these solar particles as well.

The work is now being extended to produce a world-wide grid of cutoff rigidities. A 15-by-15-degree grid has been completed and is being refined to include latitude intervals of 5 degrees. With this vertical cutoff-rigidity map, the rigidities for cosmic rays detected at any point on the earth may be determined.

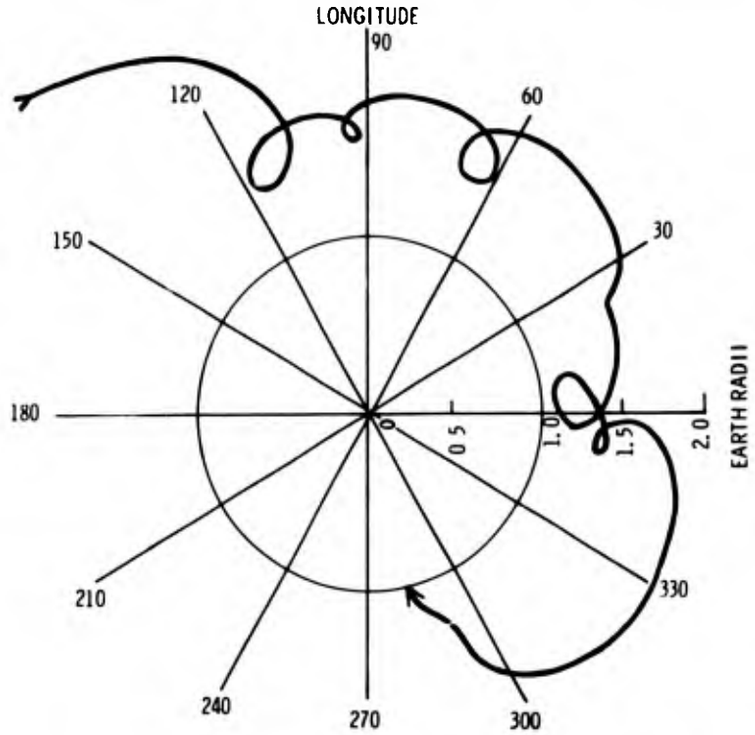

Figure 1. Typical trajectory of a high-energy particle entering the earth's influence.

REMOTE COMPOSITIONAL MAPPING OF THE MOON

In an effort to determine the feasibility of remote compositional mapping of the moon by observing the mid-infrared portion of the spectrum, the Air Force Cambridge Research Laboratories launched an automatic balloon-borne telescope-spectrometer system, and obtained the first mid-infrared (8 - 25 microns) spectrum of the moon relatively free from atmospheric attenuation.

The infrared portion of the spectrum is usually associated with heat, because heat lamps and similar devices radiate strongly in this region. Laboratory experiments at AFCRL have shown that common rock materials radiate infrared selectively at certain wave lengths. That is, rocks have infrared "colors," just as dyes are colored in the visible part of the spectrum because of the selective reflection of light. In the infrared, these rock "colors" are characteristic of composition. Because the moon has no atmosphere, solar radiation causes its surface to reach temperatures as high as 300°F. At such temperatures, the moon emits infrared radiation which can be detected and analyzed from as far away as the earth. As a result, it offers the possibility of remote compositional mapping of the lunar surface.

Unlike dyes, the "color" of rock materials gradually becomes grey as a polished surface of a rock is roughened. Common terrestrial rocks and soils present enough "color" information to permit identification of the material. If, however, the particle size of the soil approaches that of a very fine powder, or if the roughness of the rock surface assumes a microrelief equivalent to that of a fine powder, then these materials will appear uniformly "grey." Little information is available (even from Surveyor) concerning the microscopic nature of the lunar surface material, so that it is not possible, using theory alone, to predict whether ot not the moon will exhibit "color" differences.

Because the earth's atmosphere is not transparent in the infrared, a balloon-borne system was used to lift a telescope and spectrometer out of 99 per cent of the atmosphere. The system was launched by the AFCRL balloon-launch team from Holloman Air Force Base, New Mexico, on 4 February 1966. Observations of the moon began about 3 a.m. the following morning, and lasted for a little more than an hour.

The reduction of the data shows that the moon is very nearly grey, and puts an upper limit on the particle size of surface roughness, which is similar to that of clay materials.

These results have demonstrated that very little spectral information is available to distinguish between different compositions on the lunar surface, and that very sophisticated instrumentation and techniques will be necessary to obtain meaningful results with regard to remote compositional mapping of the lunar surface in the infrared.

A much-improved instrument package is currently being built which will fly on the same balloon-borne telescope system and give more precise data concerning either the particle size or composition of the lunar surface.

THE GENERALIZED HYDROMAGNETIC-IONIC THEORY

With modern improvements in absorption measurements, and the utilization of these for deriving electron density-height profiles in the ionosphere, it became clear that a more refined collisional treatment was needed than that provided by the conventional Appleton-Hartree theory, which assumes a constant electron-molecule collision frequency. The needed collisional treatment was furnished on a broad basis by Dr. Hari K. Sen's work at AFCRL on the Generalized Magneto-Ionic Theory. This theory rigorously considered

the velocity dependence of the electron-molecule collision frequency via the Boltzmann equation, and derived generalized magneto-ionic formulae, in a form convenient for practical applications, by using the laboratory result that the collision frequency is proportional to the electron energy.

The Generalized Theory is essential for considering wave propagation in the lowest ionosphere (where collisions are frequent) and, in general, for those communication problems where the wave, collisional, and gyro-frequencies are of the same order. A number of University of Alaska polar-cap absorption experiments have utilized this theory. It has been found by Barrington and Thrane that expressions like those derived from the classical magnetoionic theory are approximations which are not sufficiently accurate for interpreting cross-modulation observations. On the other hand, they found that the Generalized Theory predicts cross-modulation curves which fit the observations fairly well. Particularly for cross-modulation experiments, the assumption of constant collision frequency in the Appleton-Hartree theory is physically invalid, since it predicts zero cross-modulation.

This Generalized Theory originally applied only to a weakly ionized gas. It was later extended to a fully ionized gas, and again was recently extended by AFCRL to include ion motion as well. The formulae developed are applicable to communication problems in low-frequency wave propagation through a plasma. In particular, they will be useful for investigating the ions of the upper atmosphere, and giving a quantitative estimate of the hydromagnetic-wave dissipation in, and heating of, the solar corona. Only a qualitative estimate, so far, is available for the latter problem.

The generalization of the standard magneto-ionic theory has been brought to completion by considering the effects of partial ionization. The Generalized Hydromagneto-Ionic Theory can now be applied to all communication and propagation problems in a partially ionized gas. It fills in the gap of wave dissipation in the intermediate levels of the ionosphere, for which no present theory is available. The theory is being applied to estimate the ionospheric heating by hydromagnetic waves caused by the impact of the solar wind on the magnetosphere.

astronomy and astrophysics

ANGULAR SIZE OF BRIGHT STARS

At the Second Rochester Conference on Coherence and Quantum Optics held at the University of Rochester, 22-24 June 1966, Professor R. Hanbury Brown of the University of Sydney, Australia, reported that the angular diameters of several hot bright stars had been measured with great accuracy by the new stellar-intensity interferometer at Narrabri, New South Wales, Australia. This research is being supported jointly by AFOSR and AFCRL. The instrument employs a correlation technique not previously exploited in astronomy. For this reason the instrument is of considerable importance, not only for its use in astronomy, but also as an illustration of a form of interferometer which may have other applications, such as the measurement of line widths in spectroscopy. The purpose of the instrument is to measure the apparent angular diameter of hot bright stars. This is done by analyzing the correlations in the fluctuations in the intensity of light from the star as received by two independent mirrors, as a function of the spacing between the mirrors. From the measurements it is possible to map the distribution in intensity across the disc of the star. From this the apparent angular diameter may be inferred.

The new technique has two important advantages over the classical type of interferometer used by Michelson and his colleagues. It is not, to the first order, affected by atmospheric scintillation; and it permits the use of long base lines which are necessary to resolve hot stars.

The instrument consists of two separate mirror systems, each of which is mounted on an alt-azimuth mount carried on a truck which may be located at will on the 618-foot-diameter circular track. Thus, the distance

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between the mirrors may be adjusted from a minimum of about 30 feet to a maximum of 600 feet. The orientation of the mirrors, and their positions during observations, are continually adjusted by servomechanisms controlled by a special computer.

Each mirror assembly is about 22 feet in diameter, with a focal length of 36 feet. Each consists of 250 small spherical mirrors individually mounted on a paraboloidal frame. Each small mirror is hexagonal, about 15 inches across. The radii of the mirrors are so selected, and the mirrors are so mounted, as to bring the light to a photomultiplier located at the principal focus of the system. An interference filter with a narrow band width is interposed in the beam. (Eighty angstroms centered on 4,385 angstroms.) Because of spherical aberration and imperfections in the mirrors, the image corresponds to a circle of confusion of about 6 minutes of arc in the sky.

The instrument was first used in 1963 to measure the angular size of Vega. In this case a base line of about 30 feet was first used, and 4 larger spacings were employed for a total of about 28 hours of measurements. The correlation in fluctuations was noted as a function of the spacing of the mirror systems; and, from this, the apparent angular diameter of Vega was found to be 0.0037 seconds of arc, with a $\pm$ 5 per cent probable error. At Vega's distance, this indicates a linear diameter about 3.2 times that of the Sun.

After the angular diameter of a star has been measured, its effective surface temperature may be deduced. In the case of Vega, for example, the temperature was found to be about 9,200 degrees Kelvin; this figure agrees well with that inferred from an interpertation of the continuous background of Vega's spectrum.

The instrument has been working well for the past several years. In addition to Vega, the angular diameters of seven other bright stars have been measured thus far, including Beta Crucis, Altair, and Beta Centauri. It is expected that the Narrabri interferometer will continue to survey all stars visible at the site of the instrument that are of spectral type earlier than FO, and brighter than magnitude +2.5. Previous attempts at extending the range of the Michelson stellar interferometer had not been successful. Thus, the new method is adding greatly to our knowledge of stellar diameters and temperatures.

The construction of the instrument was financed by the Department of Scientific and Industrial Research, United Kingdom, by the Nuclear Research Foundation of the School of Physics, University of Sydney, and by the Air Force Office of Scientific Research. AFOSR also supports, in part, the research program carried out at the Observatory.

biological and medical sciences

DISORIENTATION IN SPACE

One of the hazards of aerospace flight is the occurrence of spatial disorientation. In this condition, the aerospace crew member or members are not cognizant of their actual position in space, but respond as though the horizon were displaced anywhere from several to a number of degrees from its actual position. This situation leads to inappropriate attempts to "level" the plane, although the plane or spacecraft had been flying properly before. These attempts can lead to physiological embarrassment and fatal crashes when carried out at low altitudes, or if performed long enough at higher altitudes.

In the past, much work has been done on various parts of the system by which man orients himself in space. There are several subsystems which work together to give proper terrestrial orientation in animals and men on the ground, or near enough to it to see it. Some of the main components of this orientation system are vision, the semicircular canals, and position sense from muscles, joints, and tendons. In the central nervous system, the inputs from these components are integrated, chiefly by the vestibular nuclei in the brain stem, the cerebellum, and the medial longitudinal bundle with

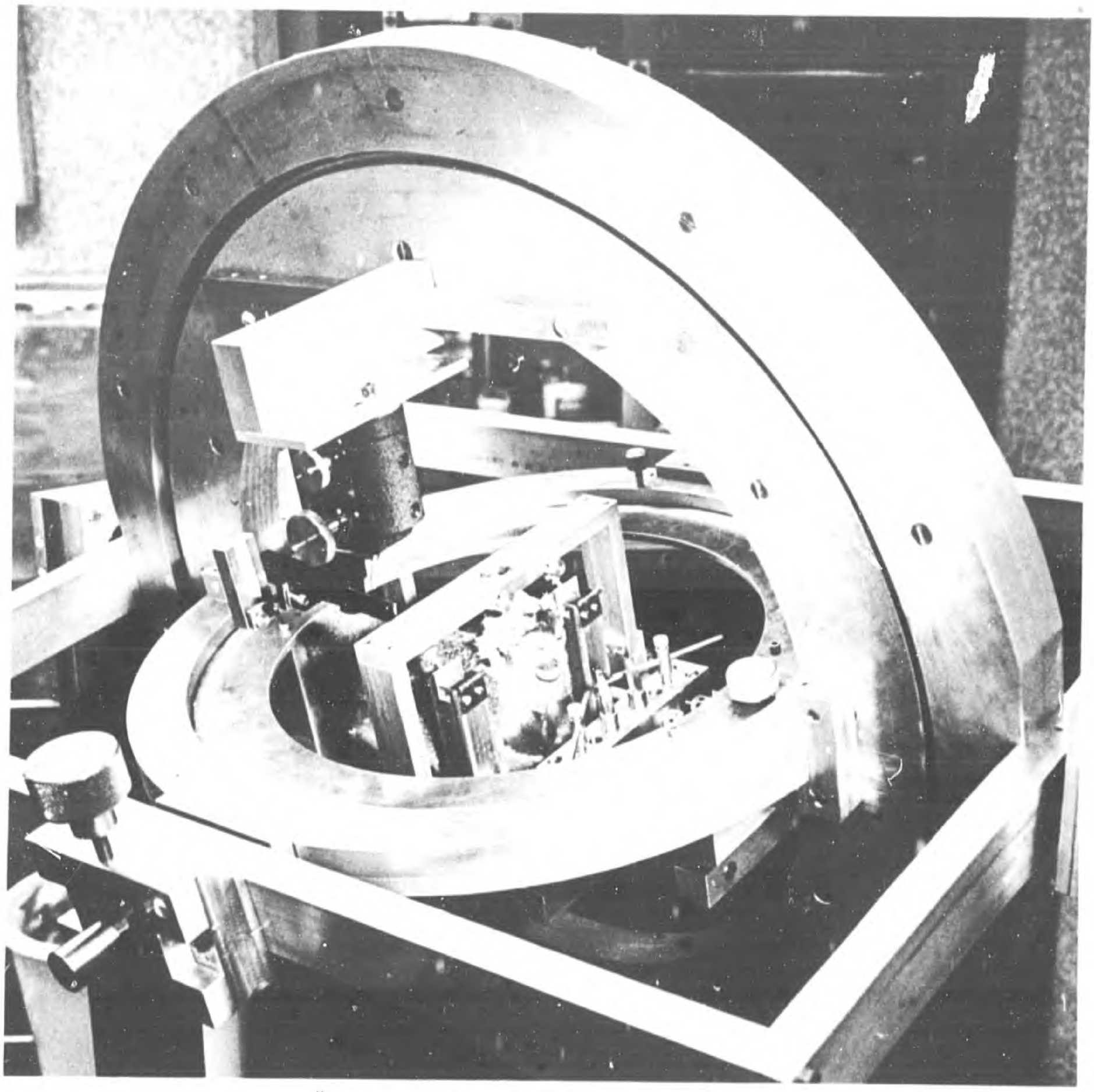

Figure 1. Apparatus for spatial orientation.

its associated motor nuclei. Each of these portions has been more or less subjected to investigation. However, the degree and amount of integration in the central nervous system has not been well studied, except for the study of symptoms, e.g., vertigo.

Dr. Gerhard Werner, an AFOSR grantee at the University of Pittsburgh, has constructed a piece of apparatus with which position in space can be precisely controlled, while joints can be extended or flexed by known amounts. The plane of any pair of semicircular canals can be achieved by the machine, so that then any pair can be stimulated by acceleration in that plane. Using neurophysiological techniques, Dr. Werner will be able to evaluate the parts played in orientation responses by any pair of canals, or by any combination of pairs, and by the stimuli coming from muscles, joints, and tendons. With this technique, the roles played by the different parts of the spatial orientation system, and also of the entire system, can be analyzed. On these bases, the symptoms and signs of disorientation can be causally explained, not conjectured.

FINGERPRINTING BACTERIA

A most interesting research program, with a broad spectrum of possible future applications, is that of General Electric chemist, John Gould, and Cornell University microbiologist, Martin Alexander. This AFOSR-sponsored program seeks to eliminate the time-consuming, laborious, and often inconclusive traditional laboratory procedures whereby various media and biochemicals are used to identify disease organisms.

Medical and clinical diagnosis have often been withheld in the past pending receipt of laboratory results, with medication for the patient being prescribed on an empirical or a clinical syndrome basis. Disease resolution, or demise of the patient suffering from an acute condition, could result prior to the receipt of pathogen identity, and selection of the most optimal antibiotic or chemotherapeutic.

Opportunities now exist for public-health workers to quickly ascertain the bacterial villain when confronted with diseases of epidemic proportions. The advantage of quickly unmasking a pathogen exotic to this country, and introduced from elsewhere in the world, is obvious. As in other forms of combat, medical combat of a disease-causing organism is dependent on the identification of that organism. This cloak of anonymity may be lost forever, since research has indicated that different bacterial genera, species, and strains each excrete metabolic wastes that are chemically distinct. These wastes are subjected to chromatography, with the separate chemical compounds passing through the chromatograph column with distinct but separate speeds. These results are then graphed out as chromatograms, thus producing a unique signature, or fingerprint, of the unknown organism subjected to scrutiny. When these chromatograms are compared with those of known bacteria, their exact identity can be ascertained.

This brief procedure is prefaced by allowing the organism in question to grow for several hours in a nutrient solution, or a support substrate. During this period, the organisms exercise their metabolic right to excrete unneeded wastes into the solution. The extracted volatile wastes are then converted by heat into their gaseous forms by the chromatograph. These gases pass through a column containing organic material which has a varied chemical affinity for the constituent molecules of the compounds being passed through the column. Segregation of entities is achieved by patterns of compounds slowed by varying chemical activity within the column. As each of these distinct compounds emerges from the column, it is recorded on a graph as the result of detection by an ionization detector. Each compound produces a distinct peak. As each compound of the total metabolic waste of a pure bacterial culture is recorded, an easily identified profile emerges. Each profile, signature, or "fingerprint" can then be compared with known signatures for purposes of identification.

Work is now progressing toward the creation of a library of bacterial signatures which, when stored in automated information-retrieval systems, will provide for an almost immediate central-file printout of the identity of an unknown organism.

The utilization of methods employing chromatography, computerized linear portrayal, and automated information retrieval will revolutionize existing methods for the detection and identification of pathogens in human and veterinary medicine. Further investigation proceeding from this research base may provide for far-reaching benefits in those fields of agriculture and industry where domesticated bacteria play valuable roles in the production of numerous and valuable chemical substances from known substrates.

Certain bacteria, such as lactic and propionic-acid bacteria important to the production of yogurt and cheese, or those neces-

sary to bring about the synthesis of butanediol from glucose and starchy substances used in the manufacture of synthetic rubber, must be maintained in pure cultures in order to achieve desired results. Industries using them are constantly on the alert to detect any contamination or changes within these domesticated stock colonies resulting from spontaneous mutations. These mutations may affect the morphology, metabolic properties or pathogenicity of the organism.

Other investigations may provide for benefits to those industries that utilize pure cultures of molds to produce many of our life-saving antibiotics. The fields of virology, and the study of rickettsia, may also benefit from future applications of this research base. The same holds true for the brewing and fermentation industries, as well for the baking enterprises, if yeasts would yield to such rapid identification methods.

The field of gnotobiotics (germ-free) research which utilizes an array of standardized biological models, i.e., the rat, mouse, guinea pig, monkey, dog, cat, and so on, would certainly benefit from the rapid detection of any organism introduced into the gnotobiotic environment.

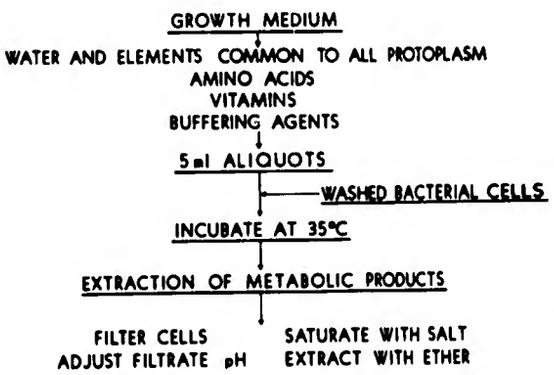

Figure 1. Preparation of test specimens.

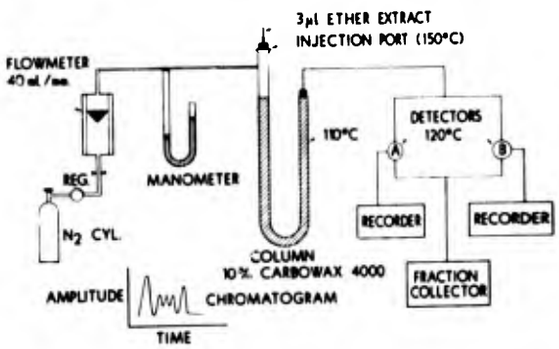

Figure 2. Gas-liquid chromatography system (dual channel)

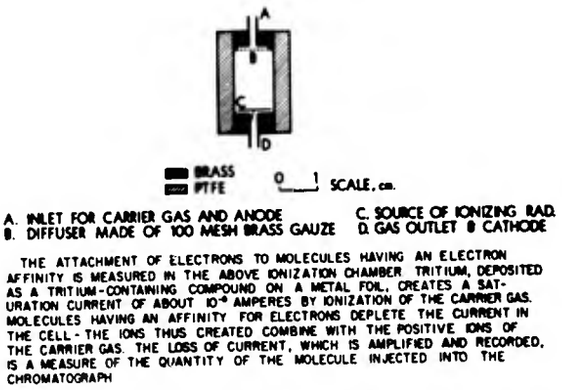

Figure 3. Electron capture ionization detector.

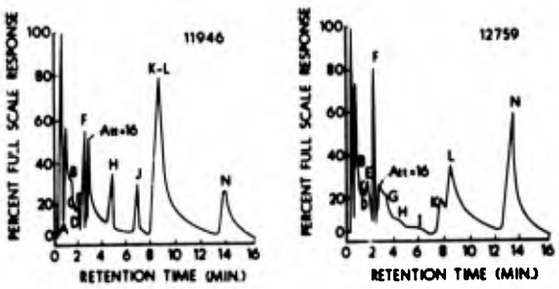

Figure 4. Bacillus licheniformis.

PEAK R_t (Sec) / STRAIN	A 39	B 60	C 80	D 95	E 106	F 150	G 205	H 287	J 359	(K,L,M) 411	N 495	799	SIGNATURE
					PEAK AREA IN mm^2								
12759	T	T	29	T	94	11800	T	T	T		1500	1041	FKNEC.abdgh
13438	T	T	T	T	37	4000					1715	215	FKNE.abcd
11946	T	T	T	T	74	5795		209	306		1670	494	FKNJHE.abcd
12713	T	T	T	T	72	9415	T	51	T	67	890	1101	FNKEJH.abcdg
9259	T		T		T	457		259				139	FHN.ace
8190	T		T	T	59	5300	T	713	T	T	2024	1624	FKNHF.acdgi
8187	T	T	T	T	33	3223		195	330		1480	528	FKNJHE.abcd
6598	T	T	T	130	T	5480		1013	95		2520	387	FKNDJ.abce
14580	790 (ETHANOL)	79 (DIACETYL)	13	33	57	3454 (ACETOIN)		T (ACETIC)		(PROPIONIC)	1930	262	FKANBEDC.h

T (TRACE) DESIGNATES A PEAK AREA OF $10\ mm^2$ OR LESS - TRACE QUANTITIES ARE REPRESENTED IN THE SIGNATURE WITH LOWER CASE LETTERS

Figure 5. Signatures of Bacillus licheniformis strains (flame ionization detector).

SENSORY FEEDBACK AND LEARNING

Following the observations of Mott and Sherrington(1) in 1895, it was generally accepted that primates deprived of skin and joint sensations are unable to walk, to climb, or to grasp small objects. Mott and Sherrington cut the sensory roots of the spinal acord of a monkey, effectively depriving the animal of sensation in one limb. In a free situation, the monkey could make no use of the sensory-denervated limb.

At the Department of Experimental Neurology, Isaac Albert Research Institute, Jewish Cronic Disease Hospital, Brooklyn, N.Y., Dr. Edward Taub, Dr. A. J. Berman, and collaborators, are successfully retraining similarly impaired monkeys to walk, to climb and to grasp small objects. Their success may be attributed to their training the monkeys to use the denervated limb when the opposite, intact limb is immobilized. They also are succeeding in training monkeys completely deprived of spinal sensory innervation.

These results have called into question many of the theories about the significance of bodily sensory input as the necessary guide to the shaping of motor responses. Further, new questions have been raised concerning the neural mechanisms responsible for response inhibition.

This experiment leads to the speculation that there may be some general applicability for the techniques here developed for converting a useless limb into one that has almost a normal function. It is possible that these techniques may provide a model for a new approach to the rehabilitation of patients who have various types of central-nervous-system lesions. Almost all present rehabilitation therapy may be described as additive in nature, based on the belief that the recovery of function can best be achieved through the re-education or exercise of inactivated muscle groups. However, the present research suggests that at least some motor deficits are caused not by the loss of nervous tissue as such, but rather by the unrestrained overactivity of certain neural centers resulting in a disabling muscular imbalance. The appropriate remedy in these cases may be a therapy whose procedures are largely subtractive, involving the restraint of various body parts while the impaired movements are practiced and retrained.

The reduction of sensory feedback through the use of the type of surgical technique employed here seems, in some ways, to be analogous to that experienced under conditions of weightlessness. When the animals, deprived of all bodily sensation, were blindfolded and placed in a monotonous auditory environment for 12 hours, they exhibited almost continuous random activity throughout the entire period. In contrast, when intact monkeys or humans are exposed to similar conditions, they spend most of the time in sleep. However, after 48-72 hours, a diffuse motor restlessness tends to develop, accompanied by an extremely unpleasant feeling in humans that "I am about to explode." The extent of sensory deprivation then appears to be the critical factor determining the time of appearance of this phenomenon, which might therefore be called the "hyposensory agitation syndrome." It does not seem to have afflicted any astronauts up to now. However, an astronaut's environment, while impoverished, does not produce so extensive a limitation in sensory inflow as in the experimental procedures described above. Thus, the "hyposensory agitation syndrome" may not emerge until the very long zero-gravity flights planned for the future are undertaken. Methods for alleviating this condition may be derived from this work.

In the years between 1940-1960, a considerable amount of research was carried out to determine the significance of sensory feedback from the muscles and joints, for the accurate manipulation of the type of controls employed in the guidance of aircraft and in various tracking tasks. In the light of the current research concerning the extent

of behavioral capacity in the absence of sensory feedback, it is not possible to evaluate the earlier results more accurately than was previously possible.

Finally, it can be said that the deafferented animal constitutes a preparation which provides one important type of base line for all functions of the organism which involve sensory-motor integration. Various Air Force missions require the performance of complex movements in environments where sensory feedback is atypical. The accumulation of a body of base-line data should be of value both for formulating antecedent evaluations of the feasibility of certain operations, as well as for increasing their efficiency.

behavioral and social sciences

RESPONSE DURING SLEEP

The possibility that learning could take place during normal sleep has generally been discredited by psychologists. Recent studies under the direction of Dr. Martin T. Orne, University of Pennsylvania, with AFOSR support, have shown that learning at some level may take place during sleep.

Dr. Orne and his associates have been investigating the individual's ability to respond to verbal suggestions during normal physiological sleep. Eighteen male students slept at the laboratory for two full nights. They were told only that the experimenter would be in the room occasionally. Continuous EEG (electroencephalograph) monitoring was carried out in order to determine the level of sleep.

After subjects had been asleep for a considerable period, and their EEG records showed that they were entering emergent Stage-1 sleep (the period in which rapid eyeball movements frequently occur and which has been associated with dreaming in several other studies), the experimenter entered the room and, in a low voice, gave simple suggestions, such as: "Whenever I say the word, 'leg,' your left leg will feel extremely cramped and uncomfortable until you move it." The cue word, "leg," was then given, both during the same Stage 1 and in later Stage-1 periods. Several suggestions involving cue words were given to each subject. Eleven of the 18 subjects responded while in Stage-1 sleep to the appropriate cue words. It should be emphasized that no instructions were given to the individual while awake. All material was presented during sleep.

On awakening, subjects who had responded were unable to recall the events which had transpired during the night. However, 7 of the 11 subjects who had responded on the 1st night responded appropriately to the cue words on the 2nd night, even though the suggestion itself was not readministered, and the subjects had no intervening waking memory of the suggestions for their sleeping responses. Further, 2 of the 7 nonresponding subjects on night 1 responded to 1 of the cue words on night 2, again with complete intervening waking amnesia. After a period of about 5 months, 7 subjects were retested on a 3rd sleep night. Five of these subjects, who had responded on both previous nights, responded again while asleep to cue words from the 2 previous nights, in spite of waking amnesia during the intervening 5 months.

This study indicates that sleeping individuals are capable of responding to verbal cues without awakening, and without subsequent waking recall. The fact that subjects would respond during the second night demonstrates that learning at some level must take place during sleep, even though it cannot be readily demonstrated in the waking state. This research has major implications for an understanding of mental functioning during sleep, and can help establish principles which may improve training techniques.

BRIGHTNESS ENHANCEMENT OF LASERS

The simple model one usually refers to in thinking of a ruby laser is that it emits optical-frequency plane waves whose transverse extent is limited by the diameter of the rod. This assumption is found to be quite incorrect when one calculates the brightness (power/unit area/unit solid angle) of such a laser and compares it to what is actually observed in practice. The measured value is about 1,000 times less than the expected one. Thus, there is considerable room for improvement of present lasers.

Insight into this major discrepancy is obtained by studying the transverse (i.e., transverse to the laser-rod axis) character of the excited electromagnetic modes; it has been found that the modes are characteristic of those of an optical resonator with curved rather than flat mirrors. These types of modes diverge much more than plane waves and result in the brightness reduction noted.

Now, if one understood the origin of the effective curvature of the presumably flat-mirror laser rods, it is possible that one could compensate for this and raise the brightness. Measurements were made of the optical properties of a laser rod during the time it was being pumped, and it was found that an approximately spherical distortion occurred in the rod because it absorbed pump energy nonuniformly. A pump light ray entering the laser rod is refracted toward its center since the rod index is higher than that of air; this simple effect causes the pump energy density, and consequently the power absorbed, to be higher in the rod center. This, in turn, causes greater expansion in the center of the rod and results in effectively curving the mirrors. It was noted that this effect was entirely reproducible. Thus, it appeared possible to compensate for this by means of an external mirror having a curvature exactly opposite to that induced in the rod.

This technique has been tried by Dr. C.M. Stickley and his group at AFCRL, and was found to be quite successful. A small ruby rod of high optical quality was placed midway between two mirrored optical flats and then pumped at a rate roughly equivalent to the rate which would be used under actual operating conditions. By measuring the frequency difference between adjacent transverse modes (modes having the same number of nodes in the longitudinal direction but different ones in the transverse direction), the degree of curvature which developed in the rod could be inferred with high accuracy. From the result of this measurement a single convex mirror was made having a curvature of 4.2 meters. Using identical pumping conditions, the substitution of this mirror for one of the flats resulted in a brightness increase of 100. In terms of getting increased power density on a target in the far field of the laser, this is equivalent to a hundredfold increase in pump rate.

This compensation process has been tried so far for only long-pulse lasers; however, it will be applied to Q-switched lasers in the near future with the hope that it will be as successful for these types as it has been for the long-pulse variety. Also, the sensitivity of this procedure to a mismatch between the rod and the external mirror curvature is not known. Further, it could be that long focal-length, planoconvex lenses with a reflecting coating on the curved surface could serve as a cheap mirror for high-power lasers.

It should be noted that this work has drawn upon a great deal of the previous research of AFCRL in this field, and that this past research was largely responsible for the success of the present effort.

The technique described above has application to all optical radar. It will enhance brightness in any application where optically pumped solid lasers are used. In addition to optical radar, military applications would include communications work in which well-aimed, bright, narrow laser beams are employed.

SOLAR-SPECTRUM-INTENSITY MEASUREMENTS FROM 30 Å to 128 Å

For a number of years, the radiation from the sun in the range of wave lengths below 1,300 Å has been measured by AFCRL using grazing-incidence monochromators with photoelectric detection on Aerobee rockets equipped with biaxial solar-pointing controls. In the region below 100 Å, the very low detector efficiency, together with a lack of suitable calibration procedures, had caused a very large uncertainty in these measurements of the absolute photon flux incident on the earth's atmosphere. Current aeronomical literature has increasingly cited the importance of the carbon VI line at 33.7 Å in the formation of the E region of the ionosphere. However, the various measurements of the absolute flux of this line reported by other experimenters has differed by a factor of 10 for similar solar conditions.

The AFCRL experiment launched 3 November 1965 on Aerobee AE 3.520 was specifically designed to extend to the 30 Å region, and to provide an absolute flux measurement of lines from 30 Å to 128 Å, with a resolution of 0.2Å. The detector used was flow Geiger counter, the recognized intensity standard for the wave-length region covered. The instrument was calibrated for absolute photon-flux measurements. The experiment acquired data above the region of significant atmospheric absorption, and the results showed clearly that the photon flux of the 33.7 Å line from the quiet sun that day was 4.3×10^6 photons $cm^{-2} sec^{-1}$, a factor of 50 lower than one previously published measurement. In addition, the spectrum contained over 100 lines, including many not seen or only marginally indicated in previous flights.

The major accomplishment of this experiment was to place the solar photon-flux measurements between 30 and 128 Å on an absolute basis during a very quiet day in the period of minimum solar activity. Future experiments during the period of increasing solar activity, and during particular solar events, can thus be referenced to a known base measurement in this aeronomically significant wave-length region. This was the first experiment to measure the absolute intensities of solar radiation in this wavelength region. Since radiation is absorbed in the earth's atmosphere, producing ionization, the knowledge gained from such measurements is important for communications purposes.

EARTHQUAKE-TRIGGERING MECHANISMS

Tests of rock behavior under conditions of high temperature and pressure have suggested two new mechanisms that may trigger earthquakes. In a recent series of laboratory experiments, using a large shear press, Dr. Robert E. Riecker of AFCRL found that the strength of a water-bearing mineral was drastically reduced when the mineral was dehydrated by heat. In another case, the crystal structure of a material changed suddenly under certain conditions. The AFCRL scientist believes that such internal changes in rock structures, rather than their slippage along faults, may be the main cause of "deep earthquakes"--those originating below the earth's outermost layer or crust.

Geologists have realized for some time that the fault theory, though adequate to explain "shallow" earthquakes (those originating in the earth's crust), had severe shortcomings when applied to deep earthquakes. In the earth's mantle, where deep earthquakes originate, pressures of hundreds to thousands of atmospheres squeeze adjoining rock structures together too tightly for them to slip along faults. Furthermore, deformation of the rock structures would

absorb these forces before slippage occurred. But, in the absence of experimental data, there was nothing to replace the fault theory as an explanation of deep earthquakes.

Such considerations have led AFCRL to study the behavior of silicate minerals, like those in the earth's mantle, at temperatures and pressures comparable to those found deep in the mantle. Previous studies of rock strength have been conducted mostly at lower temperatures and pressures. With AFCRL's high-temperature, high-pressure shear press it is possible to simulate simultaneously the pressures and temperatures found in the earth's mantle.

In AFCRL's hydraulic press, thin wafers of various minerals are squeezed between flattened tips of two tungsten-carbide anvils. Samples are heated by an induction coil. The strength of the samples is tested by slowly rotating the shaft on which one of the anvils is mounted. At low pressures, the flat tip of the rotated anvil slides across the surface of the sample much like a slipping clutch. At higher pressures, however, friction between the two surfaces is too great for slipping to occur, and the internal structure of the sample is deformed by twisting. The shear stress which produces this deformation is the same type of stress present in the earth's interior, and provides a measure of the material's strength. With this press, Dr. Riecker has been able to measure the effects of shear stress on materials at pressures of 60,000 atmospheres, and temperatures of 1000 degrees C -- conditions more extreme than have been achieved in other laboratory tests of rock strength. These conditions correspond to a depth of about 200 km.

With the shear press, the properties of a large number of minerals have been examined. Two proved to be of special interest. Each suggested a mechanism for deep earthquake formation.

One interesting material is serpentine, a magnesium silicate that contains water molecules in its crystal lattice. It was found that, at temperatures above 500 degrees, the water is driven out of serpentine's crystal lattice, greatly weakening its ability to withstand stress. Indications are that other hydrous minerals, believed to exist in the earth's mantle, may undergo a similar weakening under conditions of high temperature. Thus, an increase in temperature in a region of the mantle containing such materials could weaken them enough for existing shear stresses to trigger a cataclysmic deformation, resulting in an earthquake.

The other material is a silicate mineral called enstatite. At temperatures between 500 and 700 degrees C, enstatite changes from one type of structure to another, which occupies 10 per cent less volume. The particular temperature at which this phase change occurs depends on the pressure. However, it was discovered that this change could be brought about suddenly at much lower temperatures by applying a relatively small shear stress to the material. If such changes in crystal structure occur in materials in the earth's mantle, they could also trigger earthquakes. These experiments were undertaken to find ways to distinguish between earthquakes and underground nuclear explosions. In co-operation with the Air Force Weapons Laboratory, AFSC, Dr. Riecker is also investigating the mechanical properties of rocks at the Nevada nuclear-bomb-test site.

NOCTILUCENT CLOUDS

Noctilucent clouds are seen at unpredictable intervals during the summer in the high northern latitudes -- across Alaska, Canada, Scandinavia and the Soviet Union. (Some have recently been sighted in the Southern Hemisphere.) Occurring at altitudes of 80 km, above 99.9 per cent of the earth's atmosphere, they are by far the highest of all clouds. It has not been known why they occur only at high latitudes, and only during the local summer. Their composition has been a mystery. In the past, scientists have tended to discount the presence of water vapor at the extreme altitudes where the clouds were observed.

The first step toward explaining these

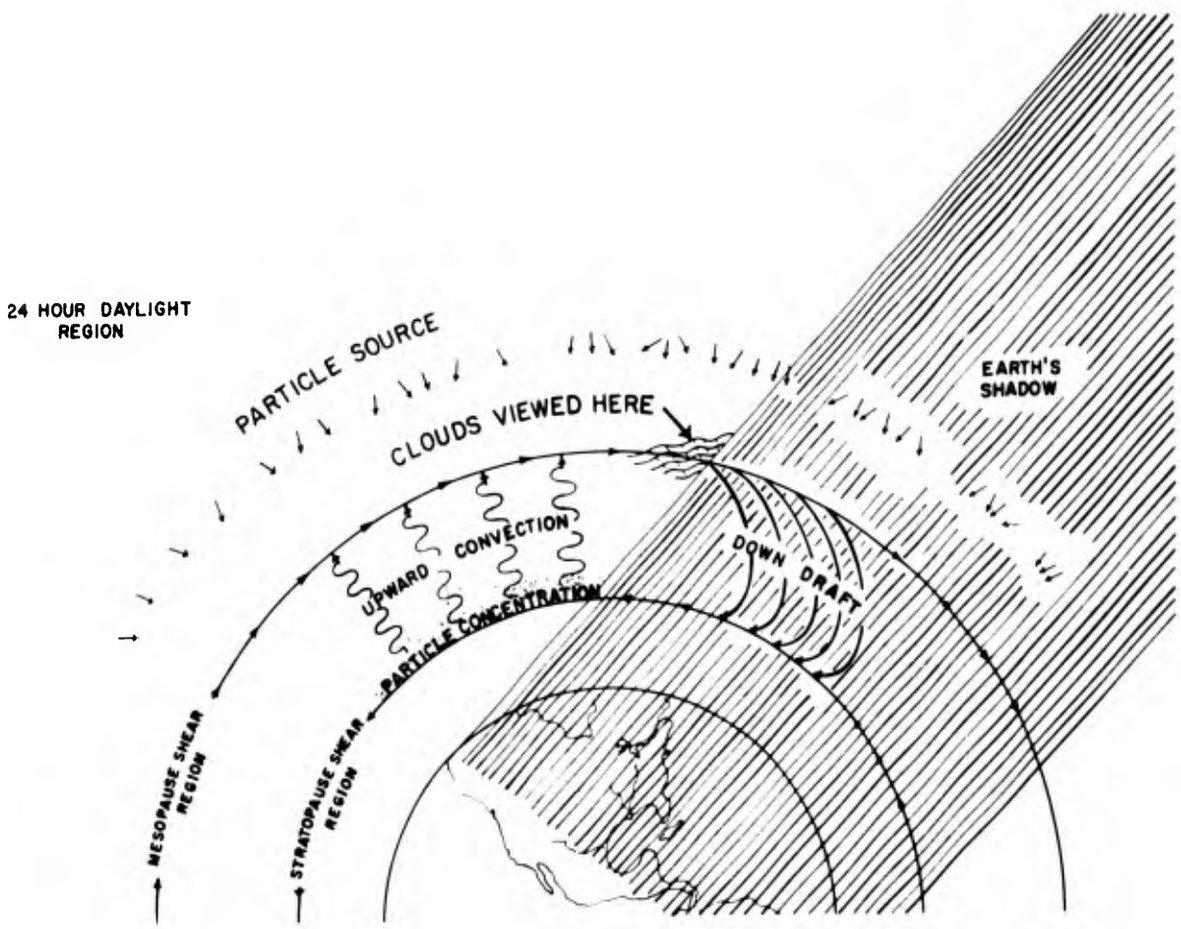

Figure 1.
The mechanism of noctilucent-cloud formation as explained by Dr. Soberman's theory.

clouds was a series of rocket flights conducted from Sweden by Dr. R. K. Soberman of AFCRL, in 1962. These rockets, with extendable collecting surfaces, were flown into the clouds and gathered samples of noctilucent cloud particles for later analysis. Flights during subsequent summers have established the fact that noctilucent clouds are composed of meteoritic dust particles which, in some cases, were covered with ice.

With this fact established, the chief remaining problems were to explain what processes could produce concentrations of this dust at such extreme altitudes, and why noctilucent clouds form only at high latitudes in the summer.

The mechanism proposed by AFCRL provides an explanation of these characteristics, and a number of other aspects of noctilucent-cloud behavior as well. Basically, the new theory is that a small updraft between 50 and 80 km keeps meteoritic dust from drifting to earth. Over a period of days or weeks, a large concentration of the dust accumulates in this altitude region. An updraft lasting long enough for such an accumulation to take place, however, could occur only under certain conditions. These conditions, summer and high latitude, are exactly those under which noctilucent clouds occur.

Under these conditions, the atmosphere undergoes the continual heating by the sun necessary to sustain an updraft persisting for weeks. It is only at or near the poles during the local summer that months of continuous daylight make this possible.

At lower latitudes, on the dark side of the earth, there would be a corresponding downdraft caused by the falling of the air cooled

in the earth's shadow. Thus, a closed system of circulation, much like a storm cell, would exist between 50 and 80 km. The sunlit updrafts of this cell would keep the meteoritic dust from falling, but would not be strong enough to lift this dust "over the top" and into the downdraft in the earth's shadow unless acted on by some outside disturbance. Hence, the dust would collect and concentrate in the updraft until such a disturbance occurred. When this happened, the particles would be raised from around 50 km to about 80 km, the altitude at which noctilucent clouds are seen.

Since this altitude change involves a corresponding temperature drop from a few degrees above zero (centigrade) to -100 degrees C, any water vapor present would freeze on the condensation nuclei provided by the meteoritic dust particles. They would then be carried along the top of the convection cell from the sunlit side into the earth's shadow. These particles, illuminated by the sun's rays coming from far below the observer's horizon, would be seen from the ground as noctilucent clouds as they pass through the twilight region.

Direct observation of this circulation pattern is unlikely since updrafts of less than half a meter per second are required to keep meteoritic dust particles (which are a few tenths to a few hundredths of a micron across) from falling. However, the theorized mechanism for noctilucent-cloud formation is subject to testable predictions. One of these, that the clouds should move from southeast to northwest in the Southern Hemisphere because of the effect of the earth's rotation on the circulation pattern, has already been verified. Another way of testing the hypothesis would be to track the clouds by means of laser radar during the daytime, when they would be otherwise invisible. A number of researchers are presently setting up laser experiments to make this test.

CHARTING AEROSOL LAYERS WITH OPTICAL PROBING

A knowledge of the atmospheric aerosol properties at all altitudes is necessary for the solution of many problems. Although there has been considerable emphasis on the use of aircraft, balloons, and rockets in this research, ground-based remote-sensing methods, such as optical probing, have great merit. First, there is the important capability of performing true in situ measurements. Then, there is the additional advantage of being able to acquire large quantities of data hour after hour, day after day, at relatively small cost.

L. Elterman of AFCRL has completed development of a ground-based, remote method for determining aerosol profiles and related parameters. The method employs a vertically pointing, narrow-beam projector fronted by a modulator with rotating venetian-blind shutters. The modulating frequency is 20 cycles/sec. A telescope, sensitive electronics, and recording devices at the Sacramento Peak Observatory, 30 km away, automatically and continually scan the beam, recording the intensity of the light scattered from the beam up to 70 km altitude.

In nearly all problems concerned with the interaction of light with the atmosphere, the aerosol attenuation coefficient emerges as an important parameter, primarily because it is proportional to the aerosol density. A determination of light-scattering as a function of altitude, using this method, permits computation of this parameter. The equations derived are reasonably complex, and require an iterative-convergent procedure for their solution. The computer output establishes the aerosol-layer structure and its properties relative to optical transmission. Based on a sampling of one year's measurements, it seems convenient to categorize the aerosol distributions into moderate-structured, median-structured, and full-structured profiles, with the last probably being in the majority.

A substantial number of measurements now make up a data bank which has application to transmission studies pertinent to optical communications, tracking and reconnaissance. The material may also provide inputs to such other investigations as nocturnal and seasonal trends of aerosol con-

centrations, effects of volcanic action, and correlation studies with radiosonde and ozonesonde measurements. These, in turn, are related intimately to various problems in applied meteorology, such as turbulence and tracing.

ground electronics

VOCAL-RESPONSE SYNTHESIZER

Speech synthesizers are electronic devices that can generate speech from an ensemble of control signals, such as those describing the fundamental pitch and inflections of the voice, the shape of the voice spectrum, whether the speech event is required to be vocalic or consonantal in nature, and the speech-intensity level. A speech analyzer that obtains such information from speech, together with the speech synthesizer to recreate the voice signal, comprise a speech-compression system that can be used for voice communications with less transmission band width and greater reliability than conventional voice-transmission methods. One type of speech-compression system is the vocoder, which is of special interest for use in digital voice communications systems where the speech compression obtained in the vocoder system permits the use of digital-data transmission at much lower transmission rates than would be possible with straight digitization of the voice message.

It was proposed by Caldwell P. Smith of AFCRL that a speech synthesizer reproducing the second-order modulations of human speech, which include the effects of frequency-, phase-, and band-width-modulations during the production of vocalic sounds, would sound more natural than prior speech synthesizer designs that have ignored these effects. While information has been sparse on these effects in speech production, and there has been no information regarding their importance for the perception of speech, it was reasoned that these effects might occur with sufficient generality to be important correlates of voice quality and naturalness.

It was therefore proposed that a synthesizer be designed and built so as to permit these modulations to be imposed on synthetic speech, and thus facilitate the study and evaluation of these effects. A model of the synthesizer was built to AFCRL specifications under contract with Texas Instruments, Inc., and has been incorporated in the AFCRL experimental multicode vocoder system.

In addition to the potential improvement in speech quality, this design avoids the need for inductors in a channel vocoder synthesizer, resulting in a reduction in size and weight. Another advantage is that this design inherently generates the fundamental pitch in the output speech, which has particular advantages if vocoders need to be connected in tandem as might be required for conference communications. Conventional channel vocoders lack the fundamental pitch, and therefore lose pitch-tracking capability if connected in tandem.

The new synthesizer produces speech with word intelligibility in the 90% range at 2,400 bits-per-second. The speech quality is superior to the prior design, while the size and weight of the synthesizer portion of the vocoder have been reduced.

Further improvement is expected from current studies of second-order modulation effects on the output quality and naturalness of the vocoder speech.

IMAGE AND SHAPE ANALYSIS

A problem that has proved exceptionally resistant to attack for many years is the quantitative analysis of shape and form in pictures. There is no objective way, for instance, to compute which of two different complex shapes is "more nearly" like a third, and to have it correspond to human or animal judgments. Similarly, there are no measures we can apply to complex scenes for gauging the amount of visual information contained in them. Both of these problems, however, are fundamental to the computer analysis of pictures, as well as to the transmission of pictures using minimum band width.

A two-pronged attack on this problem, by Harry Blum at AFCRL, is being implemented, both through new theoretical insights, and experimentally, with a unique computer system called the Image Analysis Facility. On the theoretical side, a new method of representing contours has been developed that greatly simplifies computer analysis. This method of representation is rather similar to lighting a grass fire along the contour of the shape in question and observing the progress of the fire front as a function of time. Sooner or later, the fire fronts originating from different parts of the contour will meet and extinguish each other. These lines of extinction, together with data regarding their development in time, are called the "stick," or "medial-axis," representation. The stick figure is complete in the sense that the process can be inverted to regenerate the original contour.

The accompanying figures show a computer version of the process applied to the silhouette of a dog. Figure 1 is the original, with the stick points superimposed. Figure 2 shows the computer analysis of the stick figure in which certain points are given special attention. These points, or nodes, are generally the first or last points to appear on a particular part of the stick. Figure 3 shows a vastly simplified version of the stick in which the major nodes have been connected with

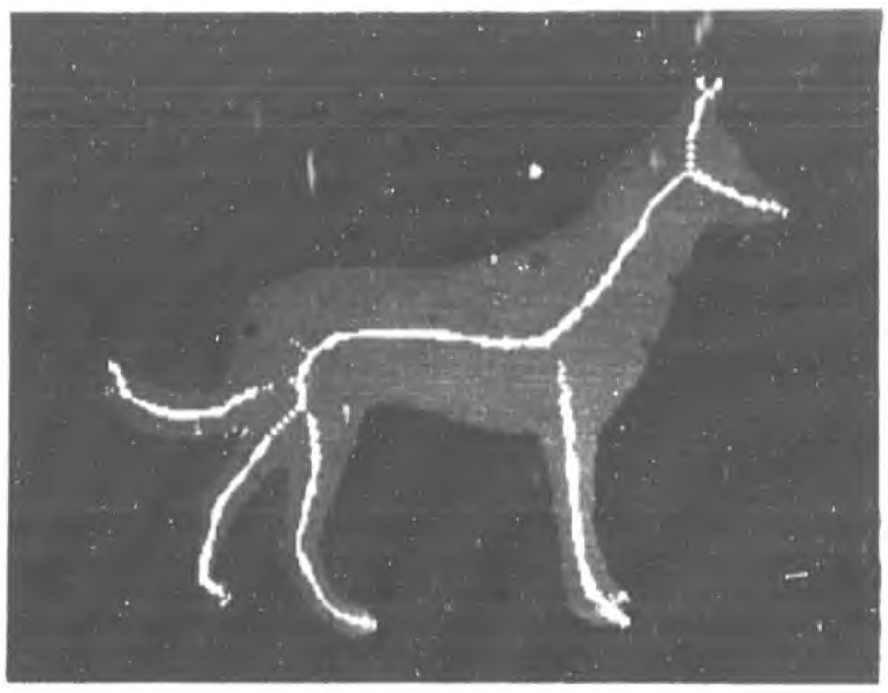

Figure 1. Original silhouette of a dog. White lines are the "stick," or "medial axis," of the image.

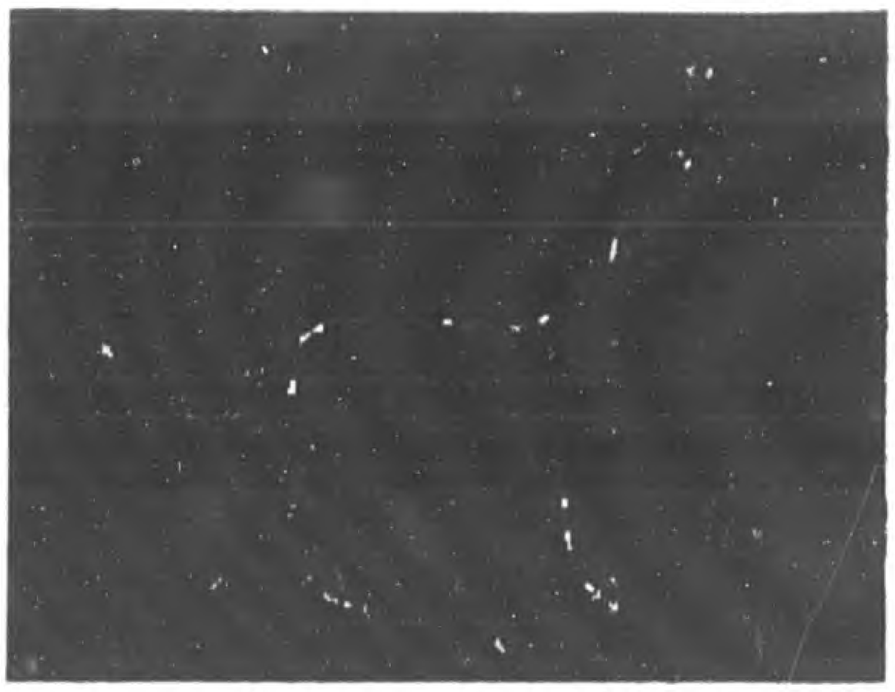

Figure 2. Computer analysis of stick figure.

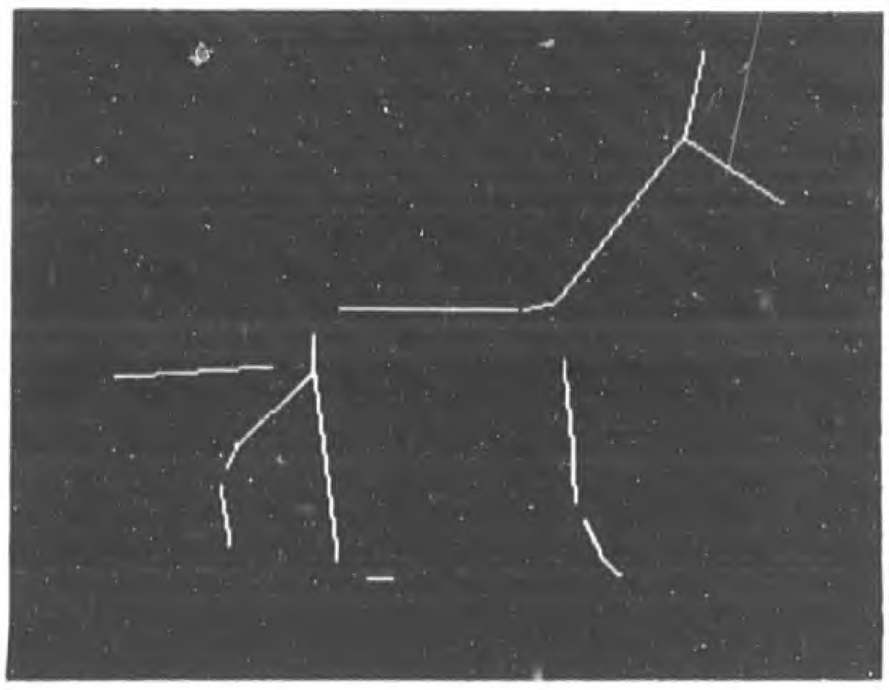

Figure 3. Simplified version of stick.

straight lines of constant velocity. Figure 4 shows the inversion of the stick of the third. The result is still remarkably doglike.

One of the applications of this process has been to the analysis of maps. The advantages are: the ease of segmentation; the ability to represent one closed contour without affecting its neighbors; the ease of answering certain questions by machine, such as "In which country does a given point lie?" and "How many countries are there?"; and the ability to measure shape features quantitatively--e.g., degrees of "corneredness," "roundness," or axial-symmetry "pinchedness" can be measured simply on the stick.

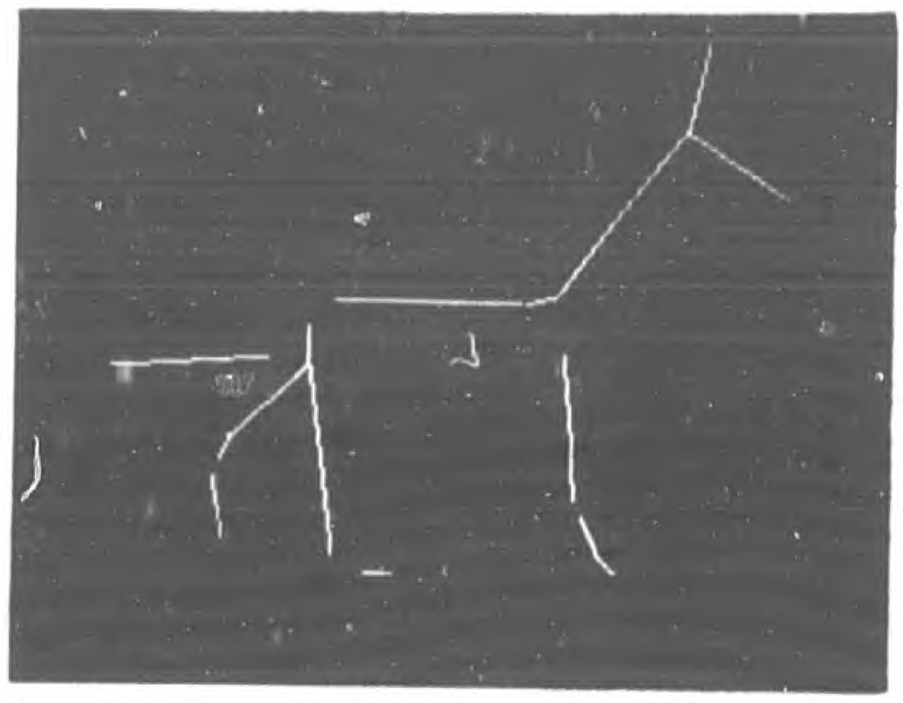

Figure 4. Inversion of stick shown in Figure 3.

studies and analysis

DEFENSE SYSTEM SENSOR SIMULATION PROGRAM

A desirable characteristic of an AICBM defense system would be the capability to defend effectively a large area with a given subset of system components ideally located far from the defended area. This capability would give the defense important advantages in flexibility and adaptability to counter an attack as it develops. The design of such a system involves the solution of many interdisciplinary problems, and the integration of these solutions to form an effective system. One of these problems is to determine the proper numbers, locations, and performance characteristics of sensors to provid. complete surveillance and tracking coverage of the ICBM threat. In a study undertaken by the Office of Research Analyses, the problems of ground-based sensor siting for area defense are being investigated. A computer program developed by Capt Henry A. Olender and Mr. Christopher A. Feuchter is being used to simulate the engagement of a representative threat with candidate sensor systems.

The program has three sets of data inputs. The first set of input data is simply a list of the co-ordinates of all ICBM launch points and all target points. The second set of input data consists of a list of trajectories between the launch and target co-ordinates which constitute the representative threat. The final set of input data consists of a list of sensors which make up a candidate sensor system. Each sensor is identified by its location, maximum range, angular sector of scan coverage, orientation of sensor scan sector, and the sensor horizon angle limit (generally a few degrees above the visual horizon).

The program selects an initial trajectory and an initial sensor, and steps a hypothetical threatening object to sequential points on the trajectory. Each point is tested to determine if it is located within the sensor coverage. If the object impacts the target without having passed through the sensor coverage, the computer notes the fact that the object or trajectory was not detected. If the object enters the coverage volume prior to impact, the computer calculates the times after launch when the object enters and leaves the coverage volume. The difference between these times is approximately the available tracking time for that sensor against that trajectory. The trajectory is then tested in this manner against each of the sensors. After all sensors have been investigated, a new trajectory is selected and the process is repeated until all trajectories have been tested against all sensors.

The outputs of this program are detailed performance results of each sensor against each trajectory, and several result summaries. The detailed results consist of a matrix, each row corresponding to one trajectory, each column corresponding to one sensor. The entries at each intersection in this matrix are the time after launch when an object entered the sensor's coverage, the time elapsed while in the coverage volume, the geocentric ground-range angles from launch point to the points of entry and exit from the sensor coverage, and the slant ranges between the sensor and the object at time of entry and exit from the sensor coverage.

There are a number of result summary outputs following the detailed printout. First, the total number of trajectories not detected and the total number of trajectories in the run are printed out. Next, a coverage-overlap matrix is printed out. This matrix gives, for all possible sensor pairs, the number of objects tracked by one sensor which were also tracked by the other sensor.

Following these summaries, tracking and acquisition-time distributions are printed out for each of 4 subsets of the detected trajectories. Each subset consists of trajectories whose apogees fall within 1 of 4 altitude bands. Thus, for each sensor and each trajectory subset, the number of trajectories tracked for between 100n and 100(n+1) seconds is printed out for n=1,2,3, . . .,15. Similarly, the number of trajectories acquired at between 200n and 200(n+1) seconds after launch is also printed out.

The final summary output is a listing of the average available tracking time and average acquisition time for each sensor against all those trajectories detected and tracked by that sensor. These results are also printed out for each of the subsets of trajectories described above.

This program is a valuable tool in the investigation of the performance of individual or netted ground-based sensors as a function of their locations, and in developing requirements for the design and location of these sensors.

exploratory development/defender

ROTATION OF THE PLANET MERCURY

At the spring 1965 meeting of the American Geophysical Society held in Washington, Gordon H. Pettingill and Rolf B. Dyce of Cornell University reported new information concerning the rotation of the planet Mercury. The latter, for many years, had been supposed to rotate the same as the Moon, so as to present the same face to its primary. Thus, Mercury's "day" was thought to be equal to its "year," that is, 88 Earth days. Now it is found that its sidereal period is 59 ± 5 days. This discovery is due to a continuing study of the planets as observed by the powerful radar of the Arecibo Ionospheric Observatory in Puerto Rico.

This Observatory is operated by Cornell University under the sponsorship of the Advanced Research Projects Agency, and is monitored by the Air Force Office of Scientific Research. The instrument employed consists of a stationary reflector of wire mesh forming an inverted spherical cap 1,000 feet in diameter. The radar signal at 430 megacycles per second has a peak power of 2 megawatts. The radar feed is movable within a cone of 20 degrees semiangle with a vertical axis. The site, at a low latitude (18°N), had been chosen so that the planets are accessible in nearly vertical direction.

Mercury was observed near its inferior conjunction in April 1965 by the Arecibo instrument. Additional observations were taken at later dates when the planet was accessible to the instrument. Analysis of radar signals reflected from the planet permitted the new determination of the period of its rotation. This is possible because the reflection from a rotating object contains a band of frequencies on either side of the central frequency, as determined by the Doppler effect. This is

the effect so often noticed when the frequency of the horn of a passing automobile is altered as the car goes by the listener. The same effect applies to radio waves. In this case, however, because the radar signal is reflected from a moving object, the Doppler shift is effectively twice as large as in the acoustic case mentioned above. Thus, the frequency of that part of the signal reflected from the portion of the planet which is rotating toward the Earth is increased above the center frequency, and that from the portion which is rotating away from the Earth is correspondingly diminished. Consequently, by measuring the spread in the frequency of the return signal, it is possible to determine the rate of rotation.

The direction of rotation was found to be the same as that of the Earth, namely, in the direction of revolution about the Sun. Since the period of revolution of Mercury about the Sun is 88 days, the interval between one sunrise on the planet and the next is about 180 Earth days. The data so far obtained are not sufficiently precise to determine the orientation of the axis of rotation; but they are consistent with the previous view that the axis is nearly perpendicular to the plane of the planet's orbit around the Sun.

The radar reflectivity of Mercury was found to be similar to that of the Moon, namely, 0.06 of that of a perfectly reflecting target of the same size. Also, it was inferred that Mercury and the Moon have about the same degree of average roughness on the scale of the radar wave length (70 cm in this case).

These results, and those previously reported on the period of rotation on Venus, illustrate the power of the Arecibo instrument in obtaining new information about the Earth's nearest neighbors. Radar observations of these objects are being continued at Arecibo. Further refinements in these findings and additional information about the Moon and other planets may be expected.

environmental research support

BALLOON-BORNE COMMUNICATIONS RELAY

The use of balloons as high-altitude relay stations for over-the-horizon UHF communications has been successfully demonstrated by AFCRL. The demonstration of balloons as relay stations for special tactical communications use took place 16 November 1965 at AFCRL's balloon-launch facility at Holloman AFB.

The balloon reached an 80,000-foot altitude where it relayed voice and teletype messages for several hours between Ft. Huachuca, Arizona and Reese AFB, Texas, a distance of about 500 miles. The test was made to evaluate a new communications system being developed by AFCRL and the Air Force Systems Command. The objective of the test program is to demonstrate techniques available for solving some of the command-and-control problems associated with limited warfare.

The balloon relay system works basically the same way as an active communications satellite. When radio relay equipment is placed at a high altitude, the line-of-sight distance between ground stations and this equipment is greatly increased, enabling it to serve as a communications link for VHF and UHF signals transmitted between widely separated points.

Distances greater than 500 miles can be obtained by using several balloons, and by floating them at higher altitudes. The maximum distance over which ground stations can communicate via a single balloon is about 780 miles--a distance determined by the 100,000-foot altitude reached by conventional balloons of moderate size and cost.

Under proper weather conditions, untethered balloons can remain virtually stationary for hours and even days, facilitating continuous, reliable communications between ground stations; balloons tethered to the

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ground are also being considered.

The basic instrument used in the test program is a compact, lightweight UHF repeater that operates at frequencies between 225-400 Mcps, receiving signals from one ground station and retransmitting them to another. This device was made by Sylvania under contract to the Air Force Avionics Laboratory. Balloon-launch facilities, support and vehicles to carry the UHF repeater aloft are provided by AFCRL under a program directed by Charles S. Tilton and James C. Payne. Ground communications equipment and technical support are provided by the Rome Air Development Center, AFSC.

Communications relays will be used on most all balloon flights conducted by AFCRL's Aerospace Instrumentation Laboratory. The relays will provide clear-channel UHF voice and data communications to ranges of 800 miles from the balloon control center to supporting aircraft and ground vehicles used for the recovery of scientific payloads. This will streamline recovery procedures and insure the effective deployment of aircraft and recovery personnel.

SCIENTIFIC PROGRESS FY 67

SCIENTIFIC PROGRESS IN FY 67

The brief articles on the following pages describe some of the research accomplished by OAR during Fiscal Year 1967 in areas of significance to the Air Force. The work includes both contributions to basic knowledge and applications of research vital to the steady technological progress of the Air Force. Although these articles treat only a fraction of the research carried out in OAR's own laboratories and in the laboratories of its contractors and grantees, they do provide some idea of the importance, variety and scope of the whole OAR research program. This will be immediately apparent from the various DoD Elements and Subelements (shown below) encompassing OAR's diverse research efforts.

Those desiring additional information on the research accomplished should consult the comprehensive Bibliography following this section.

DEFENSE RESEARCH SCIENCES PROGRAM ELEMENT 61445014

Subelements:

- General Physics
- Nuclear Physics
- Chemistry
- Mathematical Sciences
- Electronics
- Materials Research
- Mechanics
- Energy Conversion
- Terrestrial Sciences
- Atmospheric Sciences
- Astronomy and Astrophysics
- Behavioral and Social Sciences

ENVIRONMENT **PROGRAM ELEMENT 62405394**

GROUND ELECTRONICS **PROGRAM ELEMENT 62405454**

ENVIRONMENTAL RESEARCH SUPPORT **PROGRAM ELEMENT 65402124**

TEST INSTRUMENTATION **PROGRAM ELEMENT 65402154**

SUPERCONDUCTING MATERIALS

A large number of new superconducting metals have been found during the past few years. Although theoretical descriptions of the superconducting mechanisms in many of these materials have been successfully made, it has been extremely difficult to obtain fundamental theoretical insights on a general basis. An important step has been made in this effort recently by Professor Bernd T. Matthias, working at the University of California, La Jolla, and at Bell Telephone Laboratories. His research at La Jolla is sponsored by the Air Force Office of Scientific Research.

Correlations have been found between the high-temperature properties of metals and their superconducting behavior. For the elements lanthanum, protactinium and uranium a relationship is noted between the occurrence of superconductivity and lower melting points than normally expected. The critical temperatures of martensitic (diffusionless) phase transformations and superconducting transformations have been correlated in such well-known superconductors as the niobium-tin alloy, Nb_3Sn.

Now Professor Matthias has noted a correlation between hardness and superconductivity in a niobium-aluminum-germanium system. Together with scientists at the Bell Telephone Laboratories, he has observed a maximum transition temperature of 20.05°K (in the temperature range of liquid hydrogen), about two degrees higher than for any previously known material. Measurements made at the National Magnet Laboratory indicate this material may also have an extremely high critical field, which means it has a high potential for use in a superconducting magnet. (With this material, the unique properties of a superconductor could be exploited in spacecraft, using the liquid-hydrogen fuel supply for cooling.) The high transition temperature and critical field are found in a material with a composition of $4Nb_3Al:1NB_3Ge$, the same composition for which one finds an absolute minimum in the hardness for the system. Neither stoichiometry nor order parameter nor the lattice constant give any indication of the maximum superconducting transition temperature in the system at this particular combination.

A similar result was observed by Matthias and a co-worker some years ago in a zirconium-osmium system, but was not published at the time. In that case, the maximum superconducting transition temperature for solid solutions of Os in Zr occurs at precisely the concentration for which the ductility of the alloy reaches a pronounced maximum.

Thus extrema in high-temperature crystallographic transitions, in hardness, and in melting points are clearly correlated with superconducting transition temperatures. Taking this together with the empirical fact that crystals with high superconducting temperatures are frequently unstable, an interesting experimental basis for the further generalized theoretical analysis of superconducting materials has been made.

general physics

LARGE SINGLE CRYSTALS GROWN BY GEL TECHNIQUE

Large single crystals of calcium tartrate tetrahydrate ($CaC_4H_4O_6 \cdot 4H_2O$) doped with rare-earth neodymium have recently been grown by controlled diffusion in silica gel. Ranging in size up to nearly 3/4" x 1/2", these are the largest "pure" crystals ever grown by this method. Their properties are much more easily evaluated than those of microcrystals.

Techniques for growing single crystals from vapor, melt, or solution that require elevated temperatures have three inherent

difficulties: (1) crystalline imperfections are more apt to occur because of the disruption of the lattice from thermal vibrations; (2) the danger of contamination from impurities is higher because of their increased solubility with temperature; and (3) point imperfections and lattice strains are generally introduced into the crystal during cooling to room temperature.

The gel growth of crystals is the only room-temperature method for obtaining substances with low solubility in water, or low dissociation temperature, or both, that cannot satisfactorily be grown from the melt or vapor. The gel provides a three-dimensional network which permits reagents to diffuse, prevents turbulence, yields mechanically to the growing crystal, and thus avoids gross constraining forces that are more likely to arise in a crucible. The major effect of the gel is to slow down considerably the speed of the chemical reactants. As a result, crystals can grow much larger than when they are formed rapidly by a similar reaction in water.

Present emphasis is on growing large single crystals, as perfect as possible, in order to evaluate their possible applications to electronics, optics, communications, and data processing. (Figure 1.) Calcium tartrate tetrahydrate is also being investigated, both as a mechanism to better understand gel growth itself, and because it is potentially a good matrix into which dopants such as neodymium can be introduced for application to solid-state optical devices.

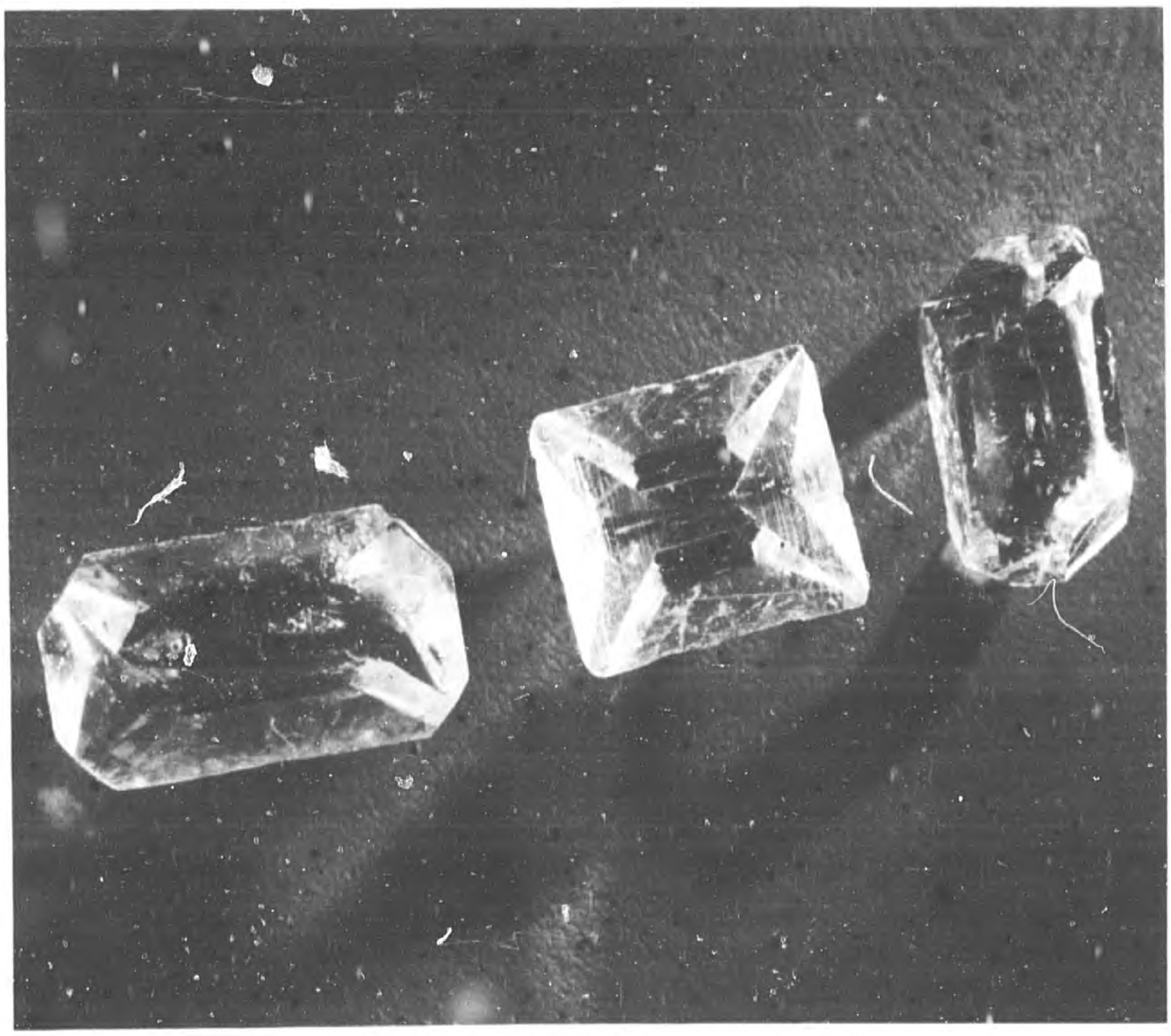


Figure 1. Gel-grown calcium-tartrate crystals (half inch).

SPECTROSCOPIC STUDIES IN A HIGH-TEMPERATURE HYDROGEN-ARC PLASMA

Arc plasmas provide a means of simulating conditions occurring in re-entry plasma sheaths, arc jet thrusters, magnetohydrodynamic generators, and the solar plasma. In the Plasma Physics Research Laboratory, ARL, a vortex-stabilized d-c arc facility has been built and is being used to simulate various plasma conditions. A hydrogen arc at atmospheric pressure and core temperature of about 20,000°C currently provides the plasma source being studied to determine the nature of the interaction processes involved. Spectroscopic measurement of the absorption and emission profile of the plasma is the principal diagnostic technique employed in determining the plasma properties.

A schematic diagram of the vortex arc facility is shown in Figure 1. The arc source is mounted on a table which has a precision scanning drive. A tracking mirror is pivoted and tracks the moving arc so as to always reflect the radiation from the brightest portion of the arc (which serves as the probing radiation) back into the spectrograph. A chopper is inserted in the mirror path and provides for alternate observation of the emitted radiation alone and the superimposed direct and reflected radiation. Current from the photomultiplier in the spectrograph is transformed into a proportional pulse rate. Thus, digital readings of the intensities are formed and recorded subsequently on magnetic tape during the scanning of the arc column. Spectral emission and absorption coefficients are then obtained using a sophisticated integral transformation of intensity values. These coefficients give the line profiles which are used to determine electron densities.

This detailed study of hydrogen, the sim-

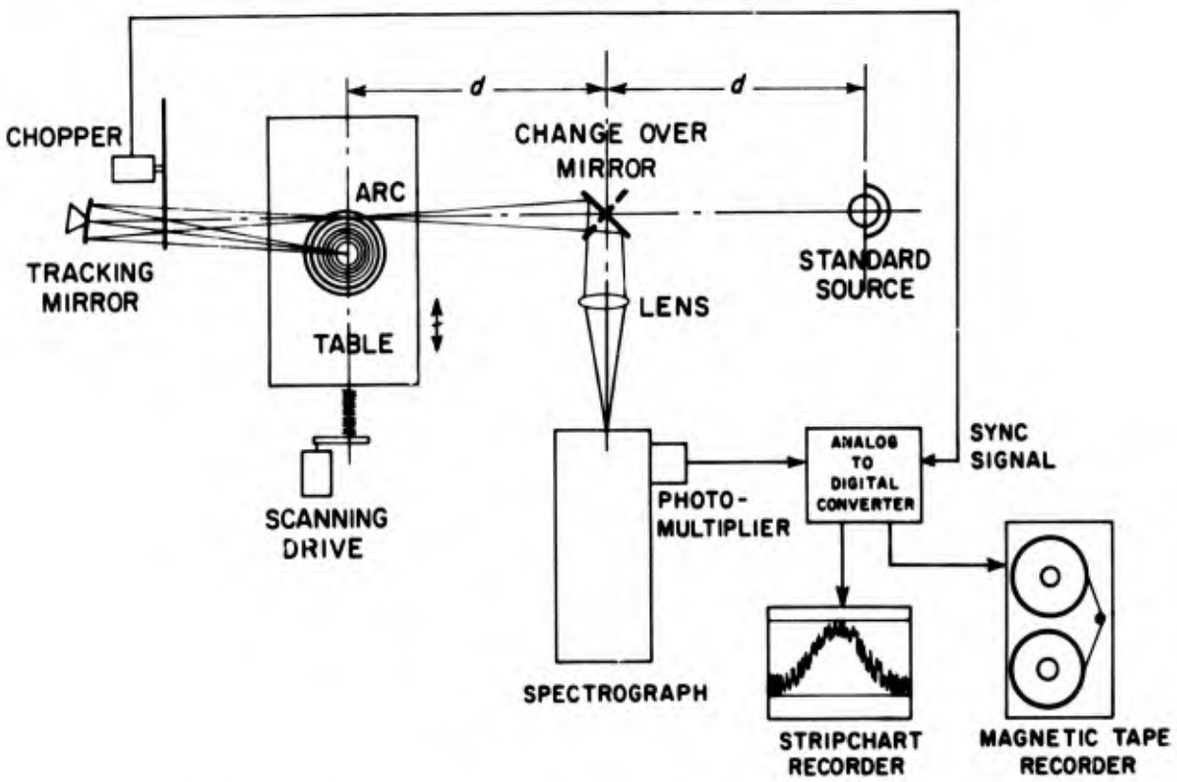


Figure 1. Vortex arc facility, Plasma Physics Research Laboratory, ARL.

plest of all atoms, is only the first phase of a broad investigation of the radiation characteristics of many gases. Instrumentation, computer programs, and operating techniques have been perfected, and the strengths and weaknesses of available theories have been identified. The next step is to include small admixtures of other gases in the now well-known hydrogen environment. Ultimately, complete radiometric data will be obtained for many elements under a variety of conditions of temperature, pressure, and concentration. The experiments already completed and reported by ARL's High Density Plasma Dynamics Group under the guidance of Dr. W. G. Braun have established this Group as a leader in the field.

ANGULAR DIAMETER OF RADIO STARS

general physics

One method of measuring the angular diameter of a radio source employs two or more receiving antennas at known distances apart. The degree of resolution obtained depends upon the wavelength employed and the geometrical spacing of the antennas. This method is called radio interferometry and is similar in principle to that of the Michelson stellar interferometer (Figure 1), used in the visible region of the spectrum. In the Michelson interferometer light from a star is reflected from two inclined mirrors at the ends of a beam mounted on the telescope tube. The light is then reflected down the axis of the telescope by two other inclined mirrors. Interference fringes are formed on the focal plane of the main mirror of the telescope. From the positions of the fringes, and the known geometry of the system, the angular diameter of the star may be calculated.

The radio interferometer (Figure 2) uses two or more receiving antennas (usually large paraboloidal dishes) and the interference fringes are formed by combining the outputs of the two antennas using one of three methods: cable, microwave link, or a new recording method to be described here. Since long baselines are needed for high angular

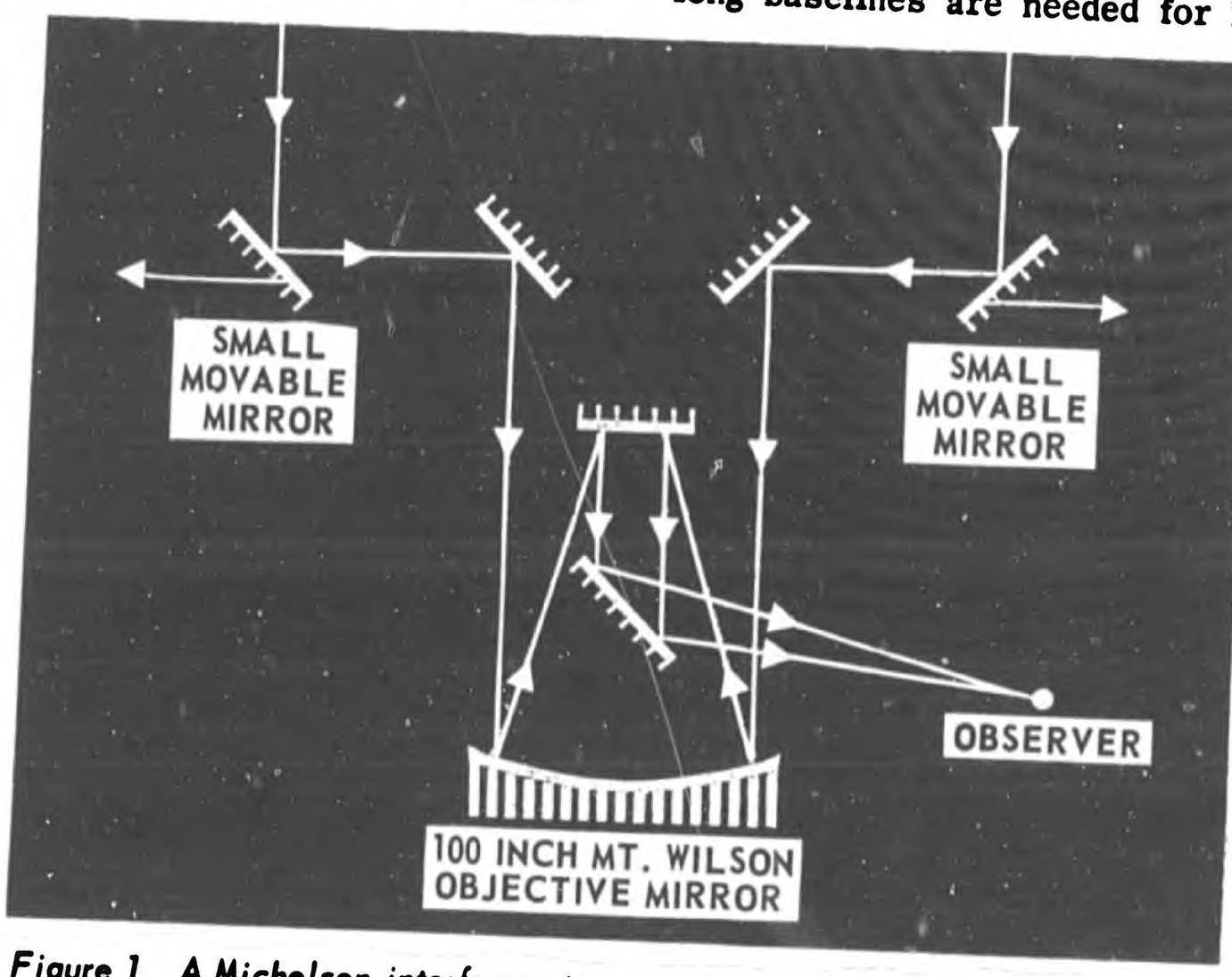


Figure 1. A Michelson interferometer consisting of 2 movable mirrors on tracks mounted on 100-inch reflector.

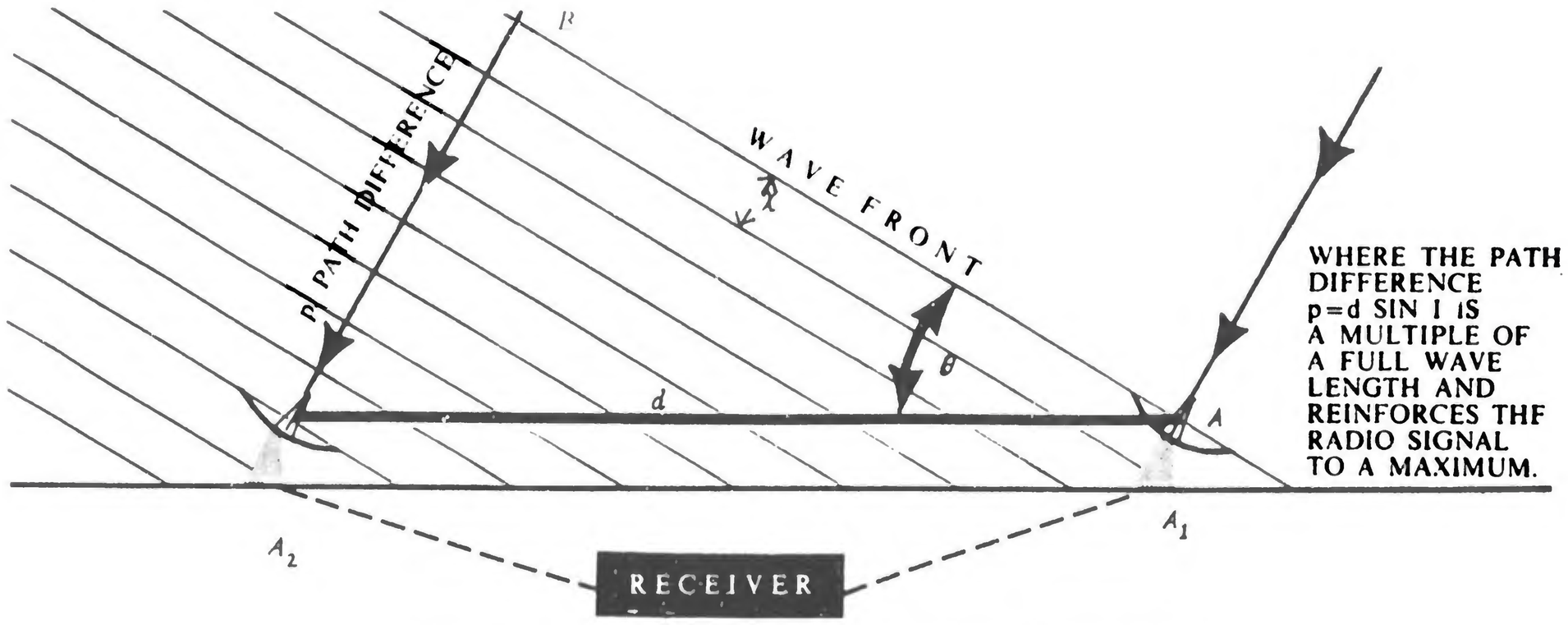


Figure 2. Schematic diagram of a radio interferometer.

resolution, the cable system is not feasible. Microwave transmission links can be used instead of cables, but this method is not suitable for baselines exceeding a few hundred kilometers because of the line-of-sight requirement in the microwave link and uncertainties in the time of transmission of the radio signals due to atmospheric fluctuations.

With the collaboration of C. Bare, B. G. Clark, and K. I. Kellerman of the National Radio Astronomy Observatory, and D. L. Jauncey of the Arecibo Ionospheric Observatory*, Professor M. H. Cohen of the University of California, San Diego, with AFOSR sponsorship, has employed magnetic-tape recordings to achieve much longer baselines than heretofore possible. A separate recorder is used at each antenna in this new method.

Coherent local oscillator signals are supplied to each element by the use of two independent highly stable atomic oscillators, one at each element of the interferometer. These oscillators consist of a high-quality crystal, controlled in frequency by a comparison with the microwave line generated by atomic transitions in rubidium vapor.

The video signal at each element is amplified and clipped. It is sampled at a 9720 kHz rate, and the resulting signal is recorded on high-speed digital magnetic tape. The sampling rate is controlled by the atomic frequency standard.

The tapes from the two stations are brought together in a digital computer, and an interferometer fringe frequency is determined.

A test of the system was provided by operation as an interferometer between the telescope at the National Radio Astronomical Observatory in Green Bank, West Virginia, and the Maryland Point Observatory of the Naval Research Laboratory. This provided an east-west baseline of about 461,000 wavelengths at 610 MHz, about 140 miles. Observations of 4 radio sources suspected of having small angular diameters were made on 8-9 May 1967. All were found to have angular diameters of a few tenths of a second of arc. Observations of other sources are continuing.

The method employed may also be used to determine the distances between the elements of the interferometer when it is known that the radio source under observation has a small angular diameter, and is thus potentially capable of measuring distance between points on the earth to the accuracy of a few decimeters, or possibly less when efforts at refining the apparatus and methods are successful. The method is particularly useful for distances so great that triangulation loses accuracy. Thus, it will be helpful in geodesy and, over a period of time, in obtaining data on the movements of land masses on the surface of the earth.

*Operated by Cornell University under a contract sponsored by the Advanced Research Projects Agency and monitored by AFOSR.

ENERGY BANDS IN II-VI SEMICONDUCTORS

The so-called band theory of solids has long been recognized as the most convenient and useful representation to describe the conduction properties of solid materials. Energy bands graphically display the allowed ranges of energy available to the conduction electrons in a solid as a function of their momentum in the crystal. Because of their great importance in describing conduction processes, accurate theoretical energy-band calculations are fundamental to constructing models which will adequately explain the many experimental observations which have been made. These calculations also provide a basis for the prediction of other phenomena which may then be checked experimentally.

Dr. T. C. Collins, Dr. R. N. Euwema and Maj. J. S. DeWitt, all of the Solid State Physics Research Laboratory, ARL, are presently engaged in performing theoretical band calculations using two related techniques: the orthogonalized plane wave (OPW) method and the pseudopotential method. The OPW method is a first-principles method in that the crystal is literally built mathematically from the ground up, using electron-wave functions which are written as Fourier-series expansions. The expansion parameters are tailored specifically to reproduce the characteristics of the electrons in the solid. A minimum of assumptions are made with the OPW method, and the basic accuracy of the results is determined by the total number of terms used in the Fourier expansions. The method is an iterative procedure in which the results may be improved continuously up to a limit set by the accuracy possible with the functions describing the electrons.

The pseudopotential method is essentially a simplification of the OPW method in which some parameters are arbitrarily adjusted (rather than calculated from first principles) to tailor the predicted results directly to the experimental measurements. Since this method is much simpler in application, it is also useful in extending the OPW calculations.

During the past year successful results have been obtained using both of these techniques. Current efforts are being devoted to applying them to a great variety of the family of II-VI semiconductors and relating the calculated energy bands directly back to the experimental observations.

COSMIC RADIO WAVES

One of the theories of the evolution of the universe states that all matter in it was at one time in a hot, highly contracted phase followed by an expansion. It is further assumed that this expansion was uniform in all directions and that it is still going on. The "red shift" in the spectrum of a distant light source is, therefore, taken to be a measure of its velocity and, inferentially, of its distance. Distances based on this theory are called "cosmological distances."

Recently, measurements in the radio-frequency regions of the electromagnetic spectrum have contributed to the evidence for this theory. Measurements of the intensity of the cosmic background radiation at several wavelengths support the idea that this radiation has a "blackbody" spectrum at about 3 degrees Kelvin--in other words, that it is characteristic of a body emitting all wavelengths with a distribution appropriate to a particular temperature. The distinction between a "blackbody" source and other sources may be explained by the example of a "red-hot" iron in the blacksmith's forge in contrast with a "neon" light which emits some colors

very strongly and is deficient in others.

The hypothesis that the background cosmic spectrum is a blackbody spectrum leads next to the idea that the universe is filled with "blackbody" radiation which is left over from the time when the universe was in a hot, highly contracted phase--a "fireball." The next question is then whether this radiation is isotropic and homogeneous. Answers to this question would permit inferences concerning the nature of the expansion and its time scale.

At the Fourth Texas Symposium on Relativistic Astrophysics, 23-27 January 1967, R. B. Partridge and David T. Wilkinson (1) reported that the asymmetry of the background radiation (of 3 degrees Kelvin) at 3.2-cm wavelength was a few tenths of one percent at most. E. K. Conklin and R. N. Bracewell (2) of Stanford University, under AFOSR sponsorship, have also found that, at 3-cm wavelength, the background radiation is isotropic to less than one fifth of one percent.

The Stanford radiometer operated at a frequency of 10,690 MHz with a bandwidth of 100 MHz. The antenna was a 60-foot paraboloid mounted so as to point to the zenith.

Both measurements are consistent with the idea that the "fireball" had a temperature several billion years ago of some 10 billion degrees Kelvin, and that it has since cooled during the expansion to about 3 degrees Kelvin. They indicate also that there are no large inhomogeneities in the matter in the universe. An upper limit of $\pm$ 10 percent is placed on the variation of density large enough to extend over a few billion light years.

general physics

ELECTRON EMISSION FROM SOLIDS BOMBARDED WITH ELECTRONS AND GAMMA RAYS

The effects of radiation on sensitive electronic systems are ultimately traceable to fundamental phenomena associated with the interaction of radiation with matter. It is important that our understanding of these phenomena be enlarged, not only to assess current problems, but also to establish a fund of knowledge which can be drawn upon when unforeseen problems arise.

The emission of electrons from materials bombarded with gamma rays and high-energy electrons is one of the basic mechanisms responsible for radiation effects observed in electronic devices. This effect is especially prominent in the vicinity of a nuclear-weapons blast and in laboratory tests. Prior to the initiation of this study, it was known that the emitted electrons tend to fall into 2 energy groups: a very-low-energy group with a peak at about 3 electron volts and extending up to 50 electron volts; and a high-energy group with energies ranging up to that of the bombarding radiation. The greatest uncertainty concerned the low-energy group. In particular, it was not possible to predict the magnitude of the low-energy emission as a function of the type and energy of the incident radiation and the nature of the bombarded material.

A review of existing theory and the limited amount of experimental data indicated that it might be possible to readily characterize emission from a given material bombarded with different radiations on the basis of energy deposited in the material, rather than in terms of emitted electrons per incident particle or photon as had been done in the past. It also appeared that the emission produced by high-energy radiations could be correlated with the extensive data available on emission produced by electrons of a few thousand volts. However, the experimental data needed to confirm these possibilities was lacking.

During the past year the emission from a number of metals bombarded with high-energy electrons and gamma rays has been studied. The results indicate that, when the emission yield is expressed in terms of the energy deposited by the incident

radiation, electron and gamma effects can be correlated. It was also found that emission produced by high-energy radiation can be predicted from the extensive data available for a large variety of materials bombarded with electrons of moderate energy. This result represents a considerable advantage in terms of guiding further research at high energies into profitable channels. It also means that the magnitude and consequences of these phenomena can now be predicted.

general physics

A SELF-MODULATING DERIVATIVE OPTICAL SPECTROMETER (SMODOS)

Working with AFOSR support, Professor Guido Bonfiglioli of the Istituto Elettrotecnico Nazionale Galileo Ferrais, Turin, Italy has developed and tested a special absorption spectrophotometer. The SMODOS consists basically of a visible range monochromator modified by the interposition of a vibrating mirror located in the light path in such a way that it emits a wavelength-modulated beam. A schematic of this instrument is shown in Figure 1.

A fraction of the monochromator light obtained through the specimen is incident upon phototube #1 and produces an amplitude-modulated current. A monitoring signal is obtained from phototube #2 which is illuminated by the remainder of the monochromator light. These signals are mixed in a circuit which produces an output proportional to the logarithm of the ratio of the two phototube currents. This output is rectified, filtered and recorded in the form of the derivative of the specimen optical density vs. the wavelength. The operation of this spectrophotometer is similar to that of an electron-spin-resonance (ESR) spectrometer; thus, it possesses the high discrimination performance characteristic of the ESR systems.

During 1967 the performance of this system has been demonstrated, and it has been shown to have a considerable advantage over standard spectroscopy systems in the detection of weak peaks masked by the side tails of stronger peaks. Theoretical calculations, including assumptions concerning peak characteristics, have indicated that this method has a capability for the detection of peaks which are 5-15 times weaker than the weakest peak detectable by standard spectroscopy. Experimental investigations for a specific test specimen have yielded a gain of 20.4 over standard spectroscopy. This gain cannot be compared quantatively with the theoretical

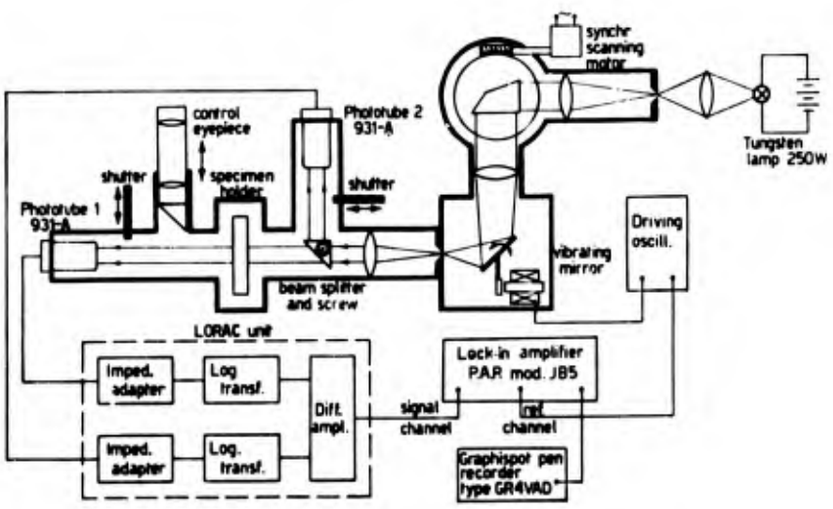


Figure 1. Schematic diagram of self-modulating derivative optical spectrometer (SMODOS).

predictions because the assumptions used in the theoretical calculations were not met in the experiment; however, this figure is certainly indicative of the gross advantage of the SMODOS technique over standard spectroscopy. This instrument will prove to be an invaluable tool in the identification and analysis of trace impurities.

nuclear physics

NUCLEAR PENETRATION BY ATOMIC ELECTRONS

One classical technique for the investigation of nuclear properties is the study of the characteristics of discrete monoenergetic electron groups emitted by energetically unstable nuclei. Such electron groups are the result of an electromagnetic process known as internal electron conversion. By means of this process the excess energy of an excited atomic nucleus can be transferred to one of the atomic electrons orbiting about the nucleus in a given shell (K, L, M, etc.). The electron is ejected from the atom with an energy equal to the change in nuclear energy minus the atomic binding energy.

Usually the internal conversion process is in direct competition with gamma-ray emission. In fact, the primary nuclear information inherent in the conversion process is contained in the ratio of the number of internal conversion electrons emitted to the number of gamma rays emitted by a given population of excited nuclei. This ratio, designated the internal conversion coefficient, is generally only a function of the nuclear transition energy, the angular momentum and parity of the emitted gamma rays, and the atomic wave function for the electron. This electron wave function can be calculated from first principles and depends on such things as the atomic number of the nucleus, the nuclear radius, and the atomic shell of the electron of interest. Extensive tabulations of internal conversion coefficients for electrons in the atomic shells K, L_1, L_2, L_3 have been published. (1, 2) On occasion, the primary electromagnetic transition process connecting two nuclear states is hindered as the result of a certain selection rule. Such hindrance effects can result in the increased importance of certain secondary effects, such as the penetration of the nuclear volume by the wave function of the atomic electron. (3) In such a case, the various conversion coefficients associated with the transition may assume anomalous values when compared with the tabulated coefficients. The study of such anomalies provides additional insights into the structure of nuclei as well as the internal conversion process itself.

In a recent study (4) at ARL, Drs. Hans J. Hennecke, J. C. Manthuruthil, K. O. H. Bergman, and C. R. Cothern discovered that the transition from the 161-keV level to the ground state of CS^{139} exhibited a hindrance of roughly a factor of 300 as compared to theoretical estimates for an M1 transition ($\Delta L = 1$, no parity change). Combining their measurements of the relative intensities of the K, L_1, L_2, and L_3 internal conversion electrons for this transition with data reported by other researchers, they have concluded that the existing anomalous results can be explained in terms of nuclear penetration effects. Further experiments are anticipated to provide added tests of the proposed penetration hypothesis.

Basic investigations of this type increase our fundamental understanding of nuclear interactions. Such knowledge possesses inherent high potential for future application of nuclear phenomena to a broad range of aerospace problems. Even though the basic nature of nuclear interactions is presently only poorly understood, the impact of nuclear phenomena on technology is evident. Future applications can be expected to arise both from developments based on present knowledge and from features of nuclear interactions yet to be discovered.

nuclear physics

PARTICLE INTERACTIONS AT EXTREMELY HIGH ENERGY

The only known interactions or forces that occur in nature are the strong interactions between nucleons, electromagnetic interactions between charged particles, weak interactions such as occur in beta decay, and the gravitational interactions between massive bodies. Experiments with high-energy particle accelerators have shown no interactions other than the above four types. However, some theories predict that all elementary particles are made of certain combinations of three basic particles (called quarks), and their antiparticles. If these theories are correct, one would expect a new type of interaction to occur in nature, i.e., the interaction between the quarks. Such interactions are called "superstrong" interactions; however, to date, neither they nor the quarks have been detected.

Perhaps one reason why superstrong interactions, whatever their origin, have not been detected is because particle accelerators are incapable of producing protons of sufficient energy. However, nature has provided its own high-energy source of particles in the form of cosmic rays, and many scientists are studying these particles to learn more about interactions at high energy. One such investigator is Professor C. B. A. McCusker of the University of Sydney, Australia, who is supported by the Nuclear Physics Division of AFOSR. Professor McCusker and his group are studying extensive air showers produced by very-high-energy cosmic rays.

At the Tenth International Conference on Cosmic Radiation held at Calgary, Canada, in June 1967, Professor McCusker reported his latest results concerning air showers which have more than one core. Multicored showers are produced when a cosmic-ray particle heavier than the proton, such as an alpha particle or even an iron nucleus, hits another nucleus in the upper atmosphere and breaks up into its constituent nucleons. His findings indicate that certain of these multicored showers have their cores separated by too great a distance to be explained by presently known forces, and that only a force much stronger than the nuclear force can account for these separations. These findings were partially confirmed by other investigators at the Conference; but further experimentation is required before they can be rigorously established. If such confirmation is obtained in the future, knowledge of superstrong forces will be of the utmost value to theoretical physicists in formulating their theories concerning the nature of matter. Increases in our fundamental understanding of the nature of matter have led to extensive technological progress in the past; further increases in this understanding are vital for future breakthroughs in technology.

chemistry

STRUCTURES OF THIN EPITAXIAL LAYERS OF ALUMINUM ON TANTALUM

Among the practical consequences of a fundamental study of the growth and properties of thin single-crystal films are better control and production of microelectronic devices and the development of better coatings for oxidation and antisputtering protection. In microelectronic devices the properties of a thin film depend markedly on conditions of preparation of the sample. Many influences are not well understood, and hence their control is more difficult. The resistivity of a thin film of tantalum, for example, can vary markedly, depending on the residual gas pressure and composition in the vacuum chamber during evaporation.

Under the direction of Dr. T. W. Haas of

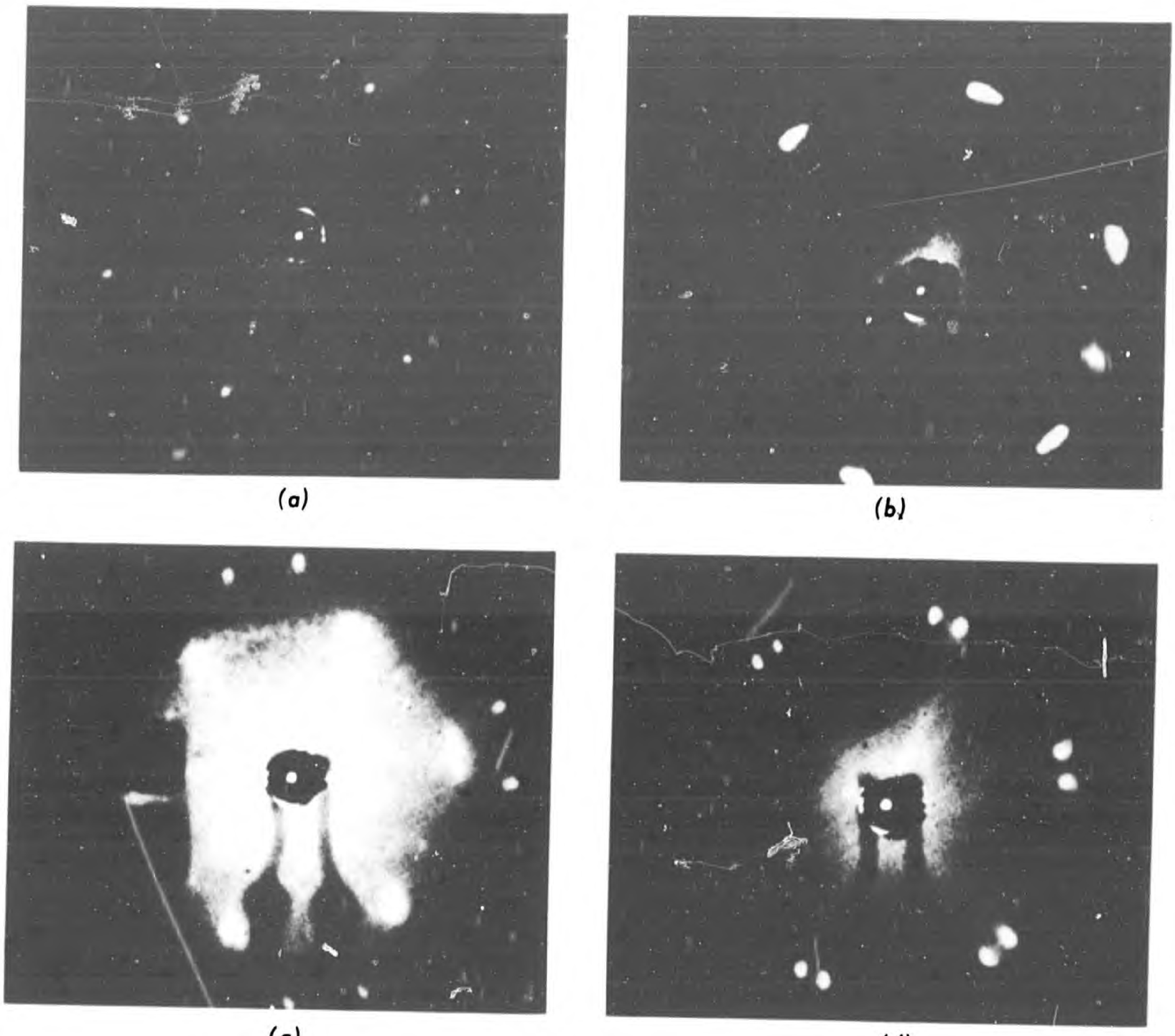


Figure 1. LEED patterns illustrating various phases obtained from the growth of aluminum on a tantalum (110) surface: (a) Pattern from a clean Ta (110) surface; (b) Pattern showing disordered Al (111) film obtained when substrate is held at room temperature during evaporation; (c) Pattern showing growth of Al (100) film obtained when sample temperature is held at 400°C during growth; (d) Pattern showing 2 orientations of well-developed Al (111) obtained by having sample at 700°C during evaporation of film. All diffraction patterns are for an incident beam voltage of 65 and for normal incidence.

ARL, and in close collaboration with Messrs. A. G. Jackson and M. P. Hooker of the Systems Research Laboratories, a program is under way at the Aerospace Research Laboratories that will attempt to relate the various conditions of the preparation of metal and semiconductor films (substrate temperature, residual gas pressure and composition, evaporation rate, etc.) to subsequent structural, electrical, and chemical properties. Low-energy electron diffraction (LEED), residual gas analysis, energy distributions of inelastically scattered electrons (plasmon excitations), and contact potential measurements are all used to characterize the films and are all carried out in the same apparatus. Initial studies in this program were aimed at understanding relatively

simple systems and, to this end, began with a study of the growth of metal films on single-crystal metal substrates. Even such simple systems can have very practical importance. One such system now under study is the growth of tin layers on a niobium crystal. This particular system is widely used in superconductive thin-film electronic devices.

The study of the growth of aluminum layers on a tantalum (110) substrate was recently completed. This relatively simple system displayed unexpected complexity as it was found that 4 different modifications of the aluminum layers were formed depending on the substrate temperature. The changes are illustrated in the LEED patterns shown. Analysis of the diffraction data shows that aluminum can be grown with its (100) or (111) plane parallel to the Ta (110) depending on the temperature of the substrate during formation. In addition, a completely diffuse amorphous phase is formed which appears to have unusual chemisorption properties. This phase seems more resistant to oxidation and chemisorption than do the crystalline layers. The existence of an amorphous layer was detected when gold and gallium were evaporated onto tantalum, suggesting that the formation of this phase is a usual rather than an exceptional occurrence. If so, important improvements in coatings may result.

chemistry

THE CHEMISTRY OF GLASS

The relevance of glass research to the Air Force stems from the many varied uses of highly specialized glasses. Air Force requirements often go far beyond those specified for civilian use. For example, the special high-strength glass fibre needed for winding Minuteman missile cases was developed under an applied Air Force contract. A very large development effort is being pursued by the Air Force and DoD in the area of composite materials. Not only are glass and vitreous silica being used, but also other filamentous materials are embedded in a polymer or light metal matrix. These new composite materials have a much higher strength-to-weight ratio than conventional metals or alloys. This qualifies them for many aerospace uses, from turbine compressor blades to helicopter rotors.

Other special but vital glasses are those used in reconnaissance photographic lenses, infrared windows for heat-seeking missiles, radar domes, electrical components for special radar and communication tubes, dielectric material for condensers and heat-proof insulation for winding compact and lightweight electric motors, and also heat- and impact-resistant glasses for the windshields of supersonic vehicles.

The history of glass-making stretches back to 2,500 B.C. with the finding of glass beads in Egyptian archeological sites. Since then the technology of glass has gradually expanded until today it is one of the most advanced in our civilization. Perhaps for this same reason the science of glass is rudimentary and in its infancy. Even such recent developments as Vycor glass and Pyroceram were empirical discoveries.

What is fundamentally lacking in the science of glass is a reasonable knowledge of the structure of glass. Today a glass is considered to have the "frozen-in" structure of the liquid, and this structure can vary with the original temperature of the liquid and also the rate of cooling to a solid glass. It is now recognized that glasses, like liquids, have more than short-range order, and lie between the disordered gaseous state and the regular crystalline solid state.

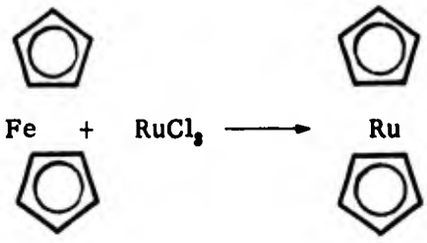
The glass program of AFOSR's Directorate of Chemistry is directed toward the central fundamental problem of the chemical structure of glasses. The reservoir of basic knowledge in this area is still almost empty, and even the need for such a pool has only recently been recognized. Dr. Charles G. Dodd at the Technical Center of the Owens-Illinois Glass Company in Toledo, Ohio is conducting a research program on "X-Ray Absorption-Edge Fine-Structure Spectrometry of Glass and Glass-Crystal Materials." Another project in the area of glass structure is being conducted by Dr. John H. Mackey, Jr. at the Mellon Institute in Pittsburgh on "Defect States and Structure of Oxide Glasses." AFOSR research was initiated in the hope of utilizing the solid-state approach to the basic chemical problem of glass structures. It was particularly relevant to Air Force interests because many lasers, photographic lenses and photochromic glasses proposed for eye protection against nuclear blasts are based on rare-earth-containing glasses. Dr. J. D. MacKenzie at Rensselaer Polytechnic Institute is directing a contract on "Viscous Flow and Compressibility of Molten Borates at High Pressure." The experimental results and the theoretical interpretations of data are being written up for publication in relation to the physical and chemical interpretations of the structures of boric oxide and sodium-borate glasses.

chemistry

SYNTHESIS OF METALLOCENES

In recent years, extensive investigations into the area of organometallic compounds of the metallocene type (metal ion "sandwiched" between two cyclopentadienide rings) have yielded a series of new monomeric and polymeric compounds having unusual stability to heat and light. (1,2) Such stability is a desirable property in many coatings and lubricants. Research generally has been confined to metallocenes of the ferrocene type, in which the central metal ion is iron, because ferrocenes are usually easier and much less expensive to obtain by established techniques than other metallocenes.

Some preliminary studies have shown that certain ruthenocenes may find special applications as light-stable ultraviolet reflector coatings. In fact, substituted ruthenocenes often exhibit improved light or heat stability compared to the corresponding ferrocenes. Recent investigations conducted at FJSRL by 1st Lt George Gauthier have concerned a novel reaction involving an exchange of the central metal ion of a metallocene for another, different, central metal ion. A reaction sequence involves the preparation of the parent ferrocene, metal exchange with ruthenium trichloride, and isolation of the resulting ruthenocene. From several simple ferrocenes, the corresponding pure ruthenocenes were prepared in significant yields. Reactions are most successful when run in a sealed evacuated tube at elevated temperatures for several days. The reaction gives only decomposition products if oxygen is present. The general reaction is illustrated below:



Ferrocene Ruthenocene

Studies of this new reaction are in their early stages. Modifications and refinements should make accessible a number of previously known and new compounds at much lower cost than present methods. The availability of such compounds should prompt further research into their applications in a variety of useful materials.

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CRYOGENIC LIQUID MIXTURES

Liquid methane (CH_4) and liquid ethane (C_2H_6) are presently being considered as advanced fuels for gas turbine and scram jet engines. Their use will allow a new generation of hypersonic aircraft to reach speeds of over Mach 5. In addition, these fuels will produce large increases in payload as compared to the normal hydrocarbon fuels. These exciting possibilities are based on such properties as their high heats of combustion and densities which combine to give fuels of high specific energy (BTU's/lb).

Important data for the use of the design engineers are being obtained through an AFOSR grant to Dr. Frank B. Canfield at the University of Oklahoma. Because of his interest in both the theory of liquids and the practical handling of liquefied fuel gases, he has developed a method for high-precision measurement of the densities of liquid methane, ethane, etc. at the very low temperatures which must be used. (1) (At atmospheric pressure, the boiling point of methane is -162°C, and that of ethane is -89°C.)

In Dr. Canfield's method, a stainless steel bomb (Figure 1) is first filled with the purified gas under high pressure. Then the bomb is connected to a quartz pycnometer (Figure 2)

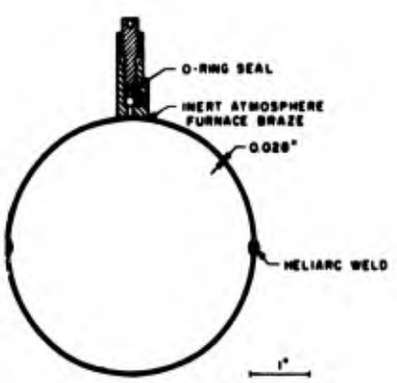

Figure 1. Weighing bomb. Specifications: valve material, type 303 ss; sphere material, PH 15-7 Mo ss; total weight, 230 g; inside diameter, 4 in; working pressure, 750 psi.

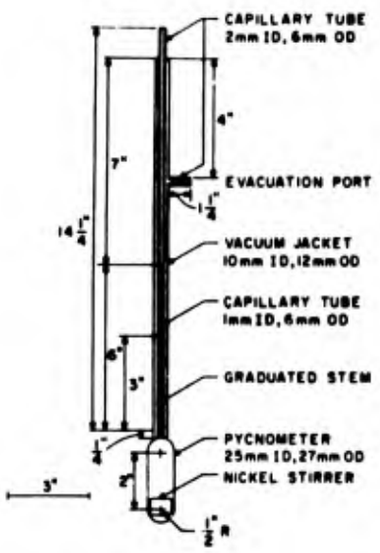

Figure 2. Schematic diagram of fused quartz pycnometer.

in a low-temperature cryostat, and gas is allowed to diffuse out of the bomb and condense in the pycnometer until the latter is exactly filled. By weighing the bomb at the beginning and the end, and calibrating the pycnometer volume by differential weighing with mercury, it is possible to determine the density with an accuracy 10 times better than previously available.

The experimental data, collected as described above, allowed the first test of the principle of congruence for liquid mixtures of n-alkanes below normal pentane. According to the principle of congruence, pure n-alkanes and mixtures of n-alkanes having the same molal average chain length should have equal thermodynamic properties at the same temperature and pressure. The molal average chain length is defined by

$$\bar{n} = \Sigma_i x_i n_i$$

where n_i is the number of carbon atoms and x_i is the mole fraction of the i^{th} n-alkane. Because of the substantial previous success of this principle when applied to the higher n-alkanes, it was somewhat surprising to

find the principle invalid for the systems investigated. The principle was found to be inconsistent with the experimental data both in predicting mixture volumes from pure component volumes and in predicting the volume of one mixture from that of another possessing the same molal average chain length. Work is now in progress on elucidating the cause of failure of this rather well-established principle.

In the more detailed molecular theory of liquid mixtures, a major problem is the prediction of interaction energies between unlike species in the mixture. Although data to test and extend existing molecular theories have yet to be collected, some preliminary work has been done on determining the interaction energies from existing data. (2)

One interesting aspect of this research, related to liquid-state theories, is the shrinkage in volume (or increase in density) that occurs when these liquefied hydrocarbons are mixed. Propulsion experts are presently considering a 90% methane-10% ethane mixture as the fuel. Dr. Canfield's fundamental research results will give the designers answers on how much saving in the size of aircraft fuel tanks can be had by using the volume-shrinkage phenomenon in these mixtures.

chemistry

BORON CHEMISTRY

The relevance of boron chemistry to the Air Force may not be apparent at first sight. However, a little investigation soon reveals a large number of highly important roles which boron and its compounds play both in current Air Force materials and also in exciting new potential uses. What is surprising is how little is known of the fundamental chemical mechanisms by which boron plays its part. Thus, since about 1940 it has been known that a minute amount of boron (of the order of about 0.001%), particularly in the presence of a deoxidizer, increases the hardenability index of steel up to 75%. Too much boron makes the steel brittle. Boron in very small amounts refines the grain of aluminum castings. In neither steel nor aluminum is the fundamental mechanism of boron's action thoroughly understood.

The incorporation of substantial amounts of boric oxide in the formulae of inorganic glasses imparts to these glasses properties of markedly increased strength, resistance to heat weakening and deformation, chemical or corrosion resistance, and other unique properties. These improved glasses are used in heat-resistant windshields and the lenses of photographic reconnaissance cameras. Improved high-strength boron glasses are used in glass fibers which, incorporated in a resin matrix, are used in winding rocket cases for advanced missiles, light heat-resisting insulation for electric motors, and other important uses. Boron and boron-carbide fibers are being studied intensively by the Air Force as a replacement for glass in new composite materials having high strength and stiffness combined with lightness. Radomes can be constructed of composite materials or out of the new glass ceramic materials of which Pyroceram is an example.

Boron catalysts such as boron fluoride and boron alkyls are used in organic chemistry, particularly in the manufacture of polymers in such materials as butyl rubber.

Boron hydrides and metal borohydrides have found wide uses in such diverse areas as organic syntheses (dehydrogenations) and paper bleaches. The remarkable and unique properties of the polyhedral boranes and carboranes with regard to their chemical and thermal stability make them very attractive candidate building blocks and intermediates for unusual polymers having possibilities of meeting the increasingly severe demands of planned and future Air Force requirements in areas such as hydraulic fluids, lubricants, O rings, and as the polymeric matrices of fibrous composite materials.

The boron program now being carried out by the Directorate of Chemical Sciences,

AFOSR, is planned to further the fundamental knowledge of boron bonding and structures with considerable emphasis in the areas of polyhedral boranes and carboranes. This has been planned to back up Air Force and Navy programs in the synthesis of inorganic polymers such as the new, extremely stable boronsilicon polymers developed with the support of the Office of Naval Research.

Dr. Alexander Kaczmarczyk, an AFOSR grantee at Dartmouth College, is exploring the chemistry of $B_{10}H_{10}^{-2}$, and has already achieved significant results. Another effort in the decaborane area is being conducted by Dr. N. N. Greenwood at the University of Newcastle-upon-Tyne in England on the reaction of transition-metal carbonyl halides with B_{10} and B_{11} polyhedral ions. Dr. T. E. Haas at Tufts University is working on nuclear-magnetic-resonance and nuclear-quadrupole-resonance studies of polyhedral borane ions. Dr. R. A. Beaudet at the University of Southern California is using microwaves to study small polyhedral boranes. Dr. D. R. Bidinosti at the University of Western Ontario is investigating boron-halide reactions mass-spectrometrically. Drs. M. F. Lappert and J. B. Pedley at the University of Sussex in England are doing a thermochemical study of certain boron reactions. Dr. M. J. S. Dewar at the University of Texas is interested in the possibility of heterocyclic organic boron compounds as semiconductors. Finally, Dr. J. D. Mackenzie at the Rensselaer Polytechnic Institute is investigating the properties of boric oxide under pressure. This research will be of value in understanding the structure of many glasses.

mathematical sciences

ATTITUDE CONTROL OF A SPINNING VEHICLE

The design of efficient attitude-control systems for extra-atmospheric vehicles is of considerable importance. The basic functions of a spacecraft attitude-control system are those of maneuvering the vehicle in a prescribed manner and stabilizing it when a desired orientation has been acquired. One important attitude-control problem is that of maneuvering a spin-stabilized vehicle where various performance criteria are considered. For example, the performance of a space-vehicle attitude-control system may be evaluated in terms of the amount of fuel consumed during a specified maneuver, or the time required to reorient a vehicle from some initial position to a desired final position.

Capt. Dirk H. deDoes of the Aerospace Mechanics Division, Frank J. Seiler Research Laboratory, has been investigating the problem of reorienting a spinning vehicle when the important design criterion is minimum time. Such a maneuver is important in certain military and scientific missions. For example, consider the problem of making rapid corrections in the orientation of a spinning re-entry vehicle during the extra-atmospheric portion of an intercontinental trajectory. During the latter phase of such trajectories, the vehicle's attitude influences a variety of parameters, including aerodynamic forces during initial contact with the atmosphere. Thus, minimum-time attitude control may be an important consideration for such mission requirements.

The problem Captain deDoes considered, having to do with time-optimal control, is one of properly orienting a spinning vehicle with respect to specified reference directions, starting from known initial conditions of the vehicle's attitude and rotation rates (1, 2). As a result, a method using sophisticated mathematical techniques was developed for computing the time-optimal control law for a wide class of vehicles in which small changes in attitude are required. This method permits the determination of the influence of such parameters as spin rate, vehicle geometry, control magnitude, and thruster configuration on the time required to optimally reorient a spinning vehicle.

As a design tool the method has an important advantage in that answers to the following questions are readily available: For a given vehicle configuration, what is the minimum time required to carry out a specified change in attitude? How do the system parameters affect the minimum reorientation time? What are the characteristics of the optimal control law in terms of the system parameters? How do various control-jet configurations compare with one another in terms of efficiency?

The method also provides a reference for evaluating the performance of nearly time-optimal control schemes. As such it provides both the time-optimal control law and the terminal time for a wide range of problems which are specified in terms of the physical parameters.

mathematical sciences

THE COMPUTER-LANGUAGE EVOLUTION

The invasion of the computer into man's routine existence becomes more apparent each day. At one time, the computer was called upon to solve the problems of a small class of scientists or specialists. Today, however, we read that the computer is performing some rather startling tasks. For example, it aids the businessman to keep his inventory up to date, it prepares our monthly bank statement, it lands astronauts safely from space journeys, and it is even being called upon to teach our children basic concepts in a wide range of subject areas.

Several years ago, it would have been unthinkable to expect the computer to perform most of these sophisticated tasks with the ease with which they are currently performed. However, we have witnessed, and are still witnessing an evolution that is enabling us to utilize the speed and power of the computer even further. The key to this evolution is our ability to communicate with the computer. Computer languages have progressed from the point where a specialist was required to encode and decode long strings of zeroes and ones (e.g., 011001101001 might have been the code that told the machine to add two numbers) to the point where an inexperienced computer user can rapidly "speak" to the computer in a language that is reasonably "natural."

Illustrative of the research that has been performed to bring about this evolution is that performed by Peter Ingerman at the Westinghouse Electric Corporation for AFOSR. Ingerman has described and developed a particular computer-language translator. His efforts have recently appeared in monograph form entitled, A Syntax-Oriented Translator.

A computer translator is a processor that accepts as input a message in one language (the language used by the programmer) and produces as output a message in another language (the computer's language) with the requirement that there exist one common meaning for the two messages. The classical translator normally is a relatively efficient structure that can provide any desired balance between fast translation and fast machine code. However, the maintenance required for the translator to incorporate changes in this balance is at best tedious work and at worst may effect a complete redevelopment of the translator. Also, the production of a new translator for a new language or for a different computer can at best make limited use of the old translation. On the other hand, a syntax-oriented translator is completely independent of the programming language that is to be translated, so long as sufficient means exist for describing the properties of the programming language. Ingerman presents a method of producing various computer languages that depends only on a system programmer's ability to specify the rules of his own language. He has, in effect, devised a method that minimizes the time delay between the conception of a new language and its availability to users of a wide variety of computers.

STUDY OF A MAGNETOPLASMADYNAMIC JET FOR SPACE PROPULSION

A multitude of low-thrust propulsion units are presently under development. These units, which include electrical, chemical and radioisotope systems, are being developed to furnish the thrust necessary for attitude-control, station-keeping and drag-makeup functions for future satellites. Research and development work on low-thrust systems is being supported by both the Air Force and NASA.

AFOSR supports basic studies in the field of plasma physics. One AFOSR investigator in this field, Dr. A. Ducati, made a research advance concerning electric-arc operation (1, 2). This research advance has resulted in the development of a new class of electric arcs, (magnetoplasmadynamic [MPD] arcs), which have demonstrated exceptionally high specific impulses up to 10,000 seconds.

AFOSR requested the Office of Research Analyses (ORA) to perform an application study of the MPD arc. This study was performed using a methodology shown in Figure 1 which was developed by ORA during the execution of a previous application study.

A survey was made of proposed future Air Force space missions to determine the thrust and total impulse requirements. The most promising low-thrust propulsion devices were selected on the basis of a literature search and discussions with engineers in the low-thrust-propulsion field. Comparative propulsion units selected were compressed gas, chemical, resistojet, radioisotope and mercury bombardment units. Three effectiveness parameters were selected: the ratio of thrust to exit area, the thrust per kilowatt power input, and system weight as a function of total impulse required. A cost model for low-altitude missions was developed to determine the cost effectiveness of using the various propulsion

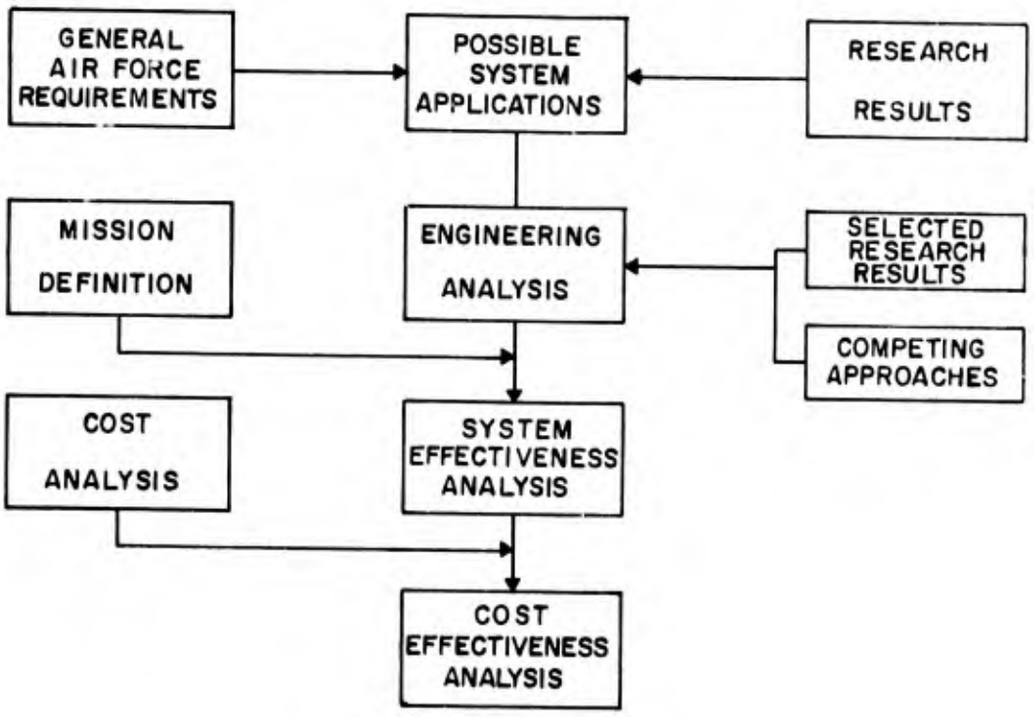

Figure 1. Research applications methodology.

units. Using resupply costs as criteria, cost-effectiveness measures were also developed for synchronous missions. The development problems facing the MPD arc were analyzed.

It was shown that the Air Force could benefit from the development of reliable, high-specific-impulse, low-thrust propulsion units. At the present time, only electric-propulsion units, such as the MPD arc, mercury and cesium bombardment and cesium contact units have demonstrated the capability to achieve high specific impulses (greater than 1,000 seconds). Therefore, the benefits that can be gained by the use of high-specific-impulse thrustors are contingent upon the development of lightweight power supplies.

Results of this application study will be disseminated to AFSC organizations. Such studies assist AFSC to recognize achievable gains in technology and improvements in systems that may result from research advances.

mathematical sciences

COMPUTATION OF SPECIAL FUNCTIONS

Mathieu functions were introduced by their originator almost a century ago, when he determined the vibrational modes of a stretched membrane having an elliptic boundary. In the intervening years, these equations have arisen during the investigation of many problems of wide scientific interest, e.g., eddy-current loss in an elliptic core, elliptic wave guides, and unsteady compressible subsonic flow past a long cylinder (air foil) of elliptic cross section. One feature in common to all of these is the elliptic shape of an element of the problem. If this shape degenerates to a circle, the problems then give rise to the well-known Bessel functions, which have been exhaustively studied and extensively tabulated. To accomplish as much for Mathieu functions was clearly out of the question, because of their added complexity; but it was felt that a major contribution could be made to the scientific community by concentrating a sizable effort on the study of these useful equations.

One portion of this effort, under the leadership of Dr. Gertrude Blanch of the Applied Mathematics Research Laboratory, ARL, has been the publication of two volumes of tables (1, 2) relating to the radial Mathieu functions, i.e., nonperiodic solutions of Mathieu's modified equation. Another portion has been the development of a generalized computer program to calculate the characteristic numbers as well as the periodic and radial Mathieu functions for real values of the parameters. This Fortran IV program, written by Mr. D. S. Clemm of the same ARL Laboratory, has also been used at the University of Michigan and the Newark College of Engineering, where a problem of wave diffraction by elliptical discontinuity is being studied.

Another class of higher transcendental functions which occur in numerous physical problems are the Elliptic Integrals and the related Elliptic Functions. The Elliptic Integrals are divided into three kinds. Those of the first kind were first encountered in the theory of large oscillations of a simple pendulum, while those of the second kind arise in the problem of finding the arc length of an ellipse (whence the name). The third kind occurs in many problems in rigid body dynamics, notably in the theory of the gyroscope. In all of the above applications, all of the parameters involved are real. The corresponding function with complex values of the parameter finds application in problems relating to conformal mapping.

Programs to compute the above-described functions have been written by Mr. Henry E. Fettis and run by Mr. James C. Caslin, both of the Applied Mathematics Research Laboratory, ARL. From these programs, for the IBM 1620 and 7094 computers, extensive tables have been compiled, comprising not only the Elliptic Integrals but also the Elliptic Functions of Jacobi (essentially the inverse functions to the integrals) for both real and complex arguments. Some of these tables have been issued as ARL

Technical Reports (3, 4, 5, 6 and 7), while others have been deposited in the Mathematical Table File of the American Mathematical Society. Copies of the tables have been distributed to all principal university and technical libraries both here and abroad.

mathematical sciences

ESTIMATING PROBABILITIES

Many complex problems can be formulated such that the nature of their solution reduces to probabilistic expressions. This is particularly true in the field of meteorology in which the Air Force has a direct interest. For example, the ability to forecast thunderstorm activity in a local area reduces to an analysis of past and current data and the use of such data in predicting either success or failure.

Dr. Richard H. Jones, an AFOSR contractor at The John Hopkins University, has done considerable research into the application of statistical methods to the field of meteorology. In a recent technical report Dr. Jones, along with Mr. William M. Brelsford has shown that, with certain assumptions on the distribution of the independent variables, the probability of a success is a logit curve, a type of sigmoid. The maximum likelihood estimators of the parameter of the logit are obtained and compared with estimators obtained by nonlinear regression techniques, both classical and a newer recursive method. A comparison is also made with a linear regression line showing the conditions under which it provides an acceptable predictor. The comparisons are made by an analysis of several types of simulated data, as well as by an analysis of meteorological data.

The comparison of several estimation methods indicates that, for a particular problem, several factors must be considered. The logit estimator has the advantage of being the easiest to calculate and provides good estimates if the model is correct. The iterative method, if it converges, converges to the maximum likelihood estimate. Recursive estimation provides an updating feature which is especially useful in real-time situations. This allows the data to be used as "independent data" to judge performance in addition to its role in determining the coefficients. The recursive estimate converges reasonably well in one pass for a moderate sample size so that the data need not be retained. This estimate is relatively independent of the initial values of the coefficients. Finally, in any problem, combinations of the three methods should be considered to obtain the optimal solution.

Binary events with continuous underlying variables (e.g., daily temperature exceeding its mean by k degrees) is another fruitful area investigated by Dr. Jones. The probability prediction is made by estimating the conditional distribution of the continuous variables and integrating over the region of interest. These results, along with other efforts of Dr. Jones in statistical research and applications, have important consequences not only for Air Force interests in meteorology but also for other areas of directly related Air Force application.

electronics

OPTIMUM TRANSMISSION OF SPEECH

Communications--the transmission and reception of information--serves its intended purpose only if a reasonable facsimile of the transmitted message can be received. The usual limiting factor is noise which has been added to the signal en route. If the amount of noise added is large, the received signal does not closely resemble the transmitted signal, and the receiver will make many errors in decoding or understanding the received message.

For data signals, a large body of techniques has evolved for the extraction of the signal from the noise. In the case of speech, however, the performance of a human receiver has not been describable in terms which would permit these techniques to be used. Further, the closest approximation to the transmitted signal is not necessarily the most intelligible.

By extending an analytic technique for determining the relative performance of a speech-communications system, Major John D. Griffiths of AFCRL has derived an optimum speech-transmission filter. The effect of the filter is to maximize the intelligibility of the speech-communications system for a particular given transmitter power and configuration. The improvement is usually equivalent to that gained by doubling the transmitter power. The filter is easily approximated by a simple RC circuit. This technique is applicable to all normal analog speech communications, such as the telephone, radiotelephone, and air-to-ground voice circuits. It effectively doubles the intelligibility "for free" by means of a reapportionment of the transmitter power within the signal. Previously, some portions of the signal carried more than their share of the communications "load," while other portions of the signal contributed little to speech intelligibility. Now, after filtering, equal amounts of signal energy carry statistically equal amounts of information.

electronics

FAR-INFRARED RADIATION SUPPRESSION

Dr. P. D. Coleman, of the University of Illinois, is pioneering research efforts in the search for high-power coherent sources in the far-infrared (FIR) spectrum under the sponsorship of the Air Force Office of Scientific Research. He is using molecular gas lasers with water or deuterium vapor as the lasing medium.

The nature of molecular lasers precludes a "clean" output spectrum, and this creates the problem of defining the lasing specie. In an effort to suppress specific spectra and enhance single lines for more accurate study, Dr. Coleman has replaced one of the resonator mirrors with a diffraction grating. The grating is adjustable, making the laser cavity highly frequency-selective. Thus, FIR can be suppressed.

The diffraction grating is an aluminum-coated material with a 52-millimeter-square, ruled area blazed at a distinct angle. The corrugated surface of the grating favors oscillation at one particular wavelength while impairing the propagation of others. Only the wavelength and harmonics that are reflected coincident with the resonator axis are allowed to oscillate as the others are scattered off-axis by the grating. The cavity may be tuned for a variety of distinct wavelengths by adjusting the position of the grating. The result of this frequency selectivity is the suppression of unwanted radiation. Figure 1 illustrates the technique used.

Since all wavelengths but one are suppressed, more energy is available for the desired transitions, and the competition be-

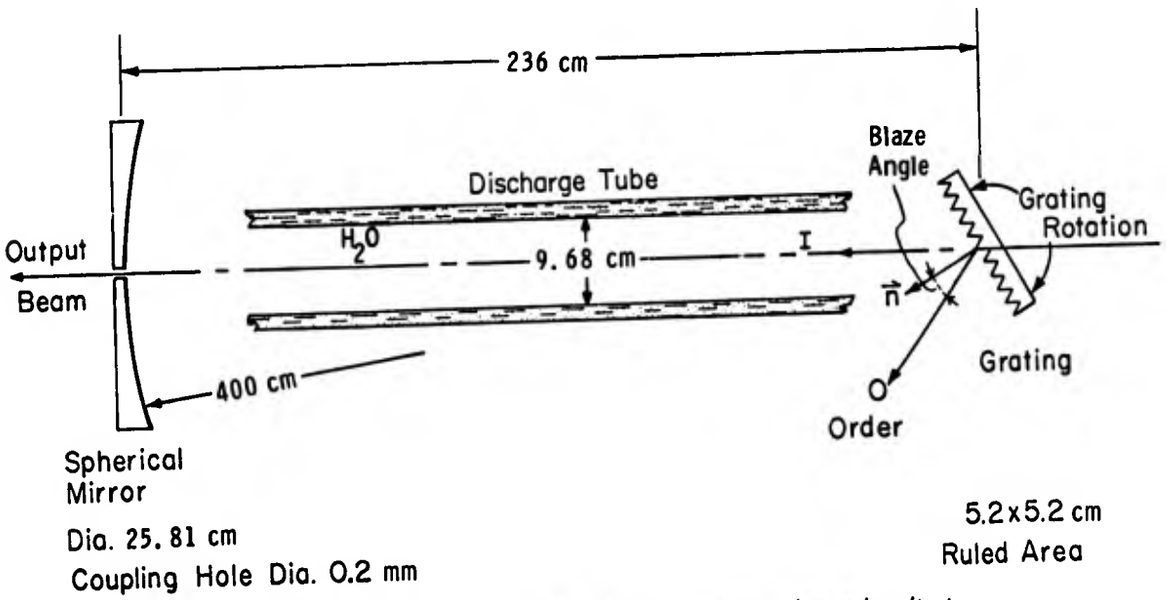

Figure 1. H_2O laser with device to suppress undesired radiation.

tween several different transitions is eliminated. Only the desired frequencies have significant gain. This effect is proved by the obvious enhancement of the selected line. The resultant selective data are consistent with the hypothesis that the H_2O molecule is the lasing specie.

The concept of suppression offers a promising technique for power enhancement in the FIR, as well as filtering the output of molecular lasers. The success of Dr. Coleman's research suggests possible applications for IR sources in countermeasures and reconnaissance. This research is highly relevant to Air Force needs, and enjoys continued AFOSR support.

electronics

HIGH-EFFICIENCY DIODE LASERS

Injection or diode lasers are of great interest because of their inherent suitability for lightweight, low-power communications and observation systems. Since injection lasers operate by the direct conversion of d-c input current to optical coherent radiation, their conversion efficiency tends to be much higher than either gas or solid lasers. There is, however, a major problem in heat removal because injection lasers are so small (typically $10 \times 20 \times 3$ mils). Also, at present, continuously operating injection lasers must be used at cryogenic temperatures. Improvements in efficiency, threshold current, and heat removal are necessary to increase the maximum operating temperature. A room-temperature laser operating in the near-infrared would permit the design of a lightweight, portable system for secure communications or forward ground-observer operations.

In a joint research program, J. E. Ludman of AFCRL's Solid State Sciences Laboratory and K. M. Hergenrother of Northeastern University have made lasers with output approaching 3 watts (continuous operation) and with about 15% efficiency at maximum power and at liquid-nitrogen temperatures. (As usual, output is from the front face only.) This is a significant improvement in the state of the art; it is 3 times more powerful and 50% to 100% more efficient than the best diodes previously reported. The lasers are made by diffusing zinc into n-type (4×10^{18} atoms/cm) GaAs to form a junction 5-8 μ deep. The first diffusion is followed by a

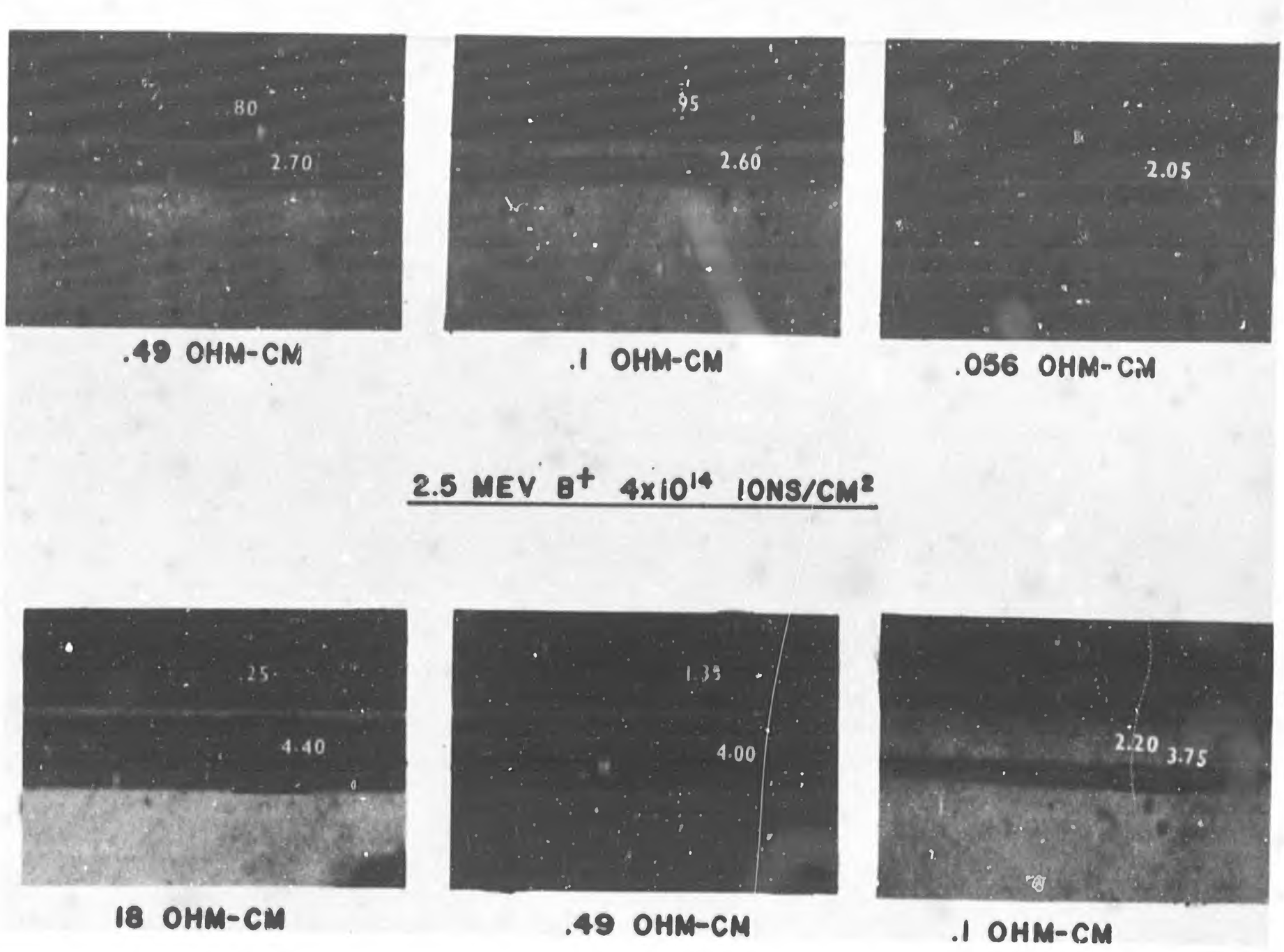

Figure 1. Profiling samples. Buried layers in varying resistivity n-type base materials formed by B^+ implantations at 1¼ and 2½ MeV revealed by 5° angle lapping and staining.

second long diffusion (2 hrs.) at an elevated temperature (1,000°C), with the source of zinc removed. Since there is no source of zinc present in the second diffusion, the junction moves less than 1 μ during the diffusion. If a deeper junction is desired, a third diffusion may be used with a source of zinc. Devices made with or without the third diffusion have high outputs and low thresholds. Without the long diffusion, junctions of 5–8 μ will not lase. The reason for the effects produced by long diffusion are not yet clear; but experiments indicate that the change in the doping profile and the removal of much of the interstitial zinc during the long diffusion are not critical.

These diode lasers, which have average power outputs greater than most ruby lasers, show great potential. Their ease of modulation, high pulse powers, and high average powers make them ideally suitable for many military as well as civilian applications.

PLASMA INFORMATION DISPLAY AND STORAGE SYSTEM

A plasma display device has been developed under the Joint Services Electronics Program by Dr. D. L. Bitzer of the University of Illinois. The novel feature of the invention is the use of a gaseous plasma discharge for a memory device. Binary data are represented by the conducting and nonconducting states of the plasma. Display characteristics can be modified by the use of any of several different gases which emit light when excited.

The gaseous plasma discharge storage and information display system consists of rectangular arrays of plasma discharge cells. One current model uses 1,600 cells per square inch. Figure 1 illustrates the construction of the device. Parallel rectangular sheets of glass are pressed together. Three edges of the sandwich are then sealed; the fourth edge provides access for evacuation and introduction of the desired gas. Each discharge cell is a small cylinder which can be separately excited as shown in Figure 2. A typical readout is shown in Figure 3 on an 8-cell × 8-cell panel.

A computer-derived binary signal together with an unmodulated alternating voltage cause the transition of a cell from one state to the other. The memory function is dependent upon the alternating unmodulated voltage. Voltage frequencies between 100 kHz and 500 kHz have been used.

Several characteristics of such a display give promise for applications. The optical display of theoretically unlimited size is a unique feature. In addition cost, flexibility, and computer compatibility provide distinct advantages in some systems. For example, for PLATO (Programmed Logic for Automatic Teaching Operation), which has severe display requirements, a cathode-ray tube display could cost a factor of 10 more. The display brightness, the fact that there is no requirement for image regeneration, and the direct use of binary data are other advantages which might be critical in particular applications.

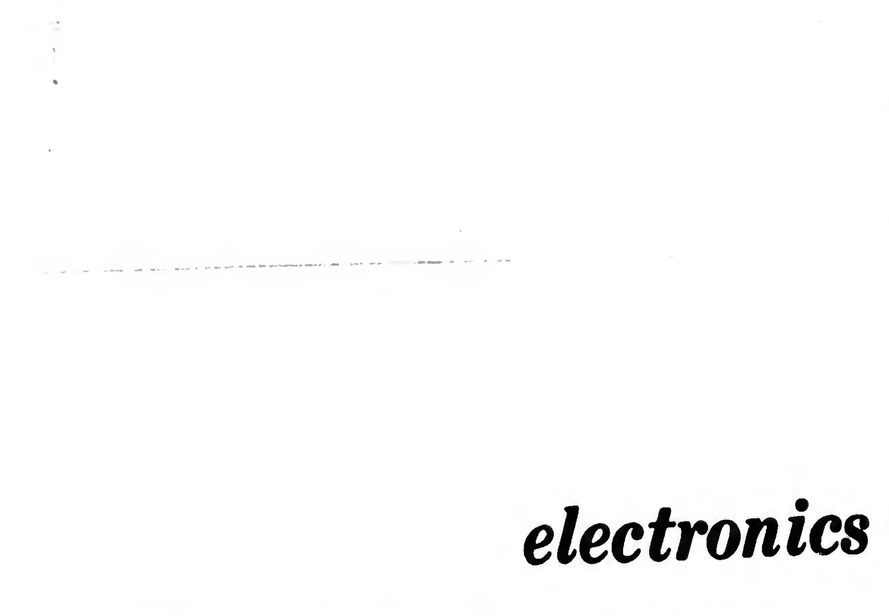

Figure 1. Assembly of plasma display panel.

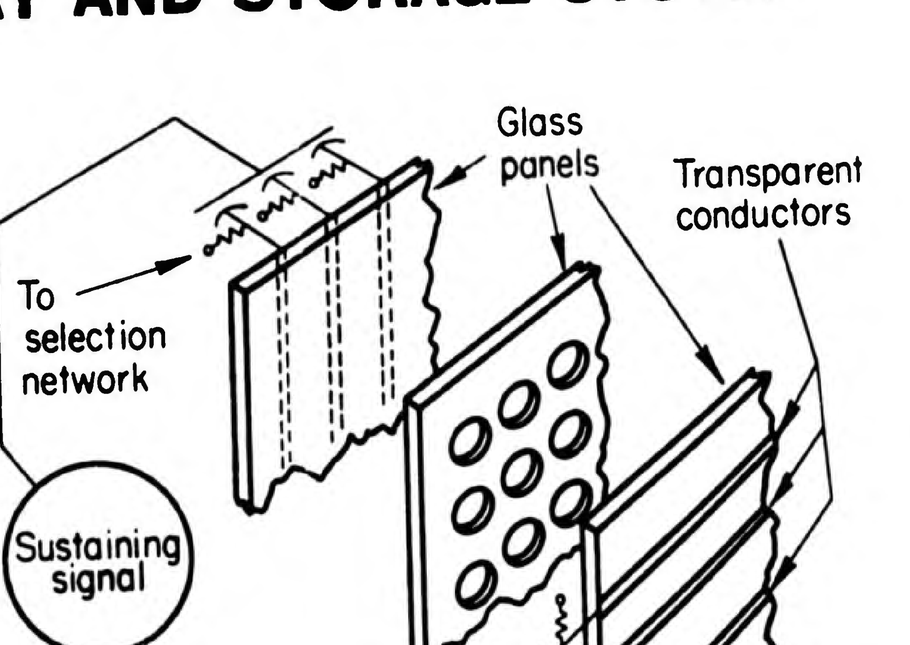

Figure 2. Gas discharge cell.

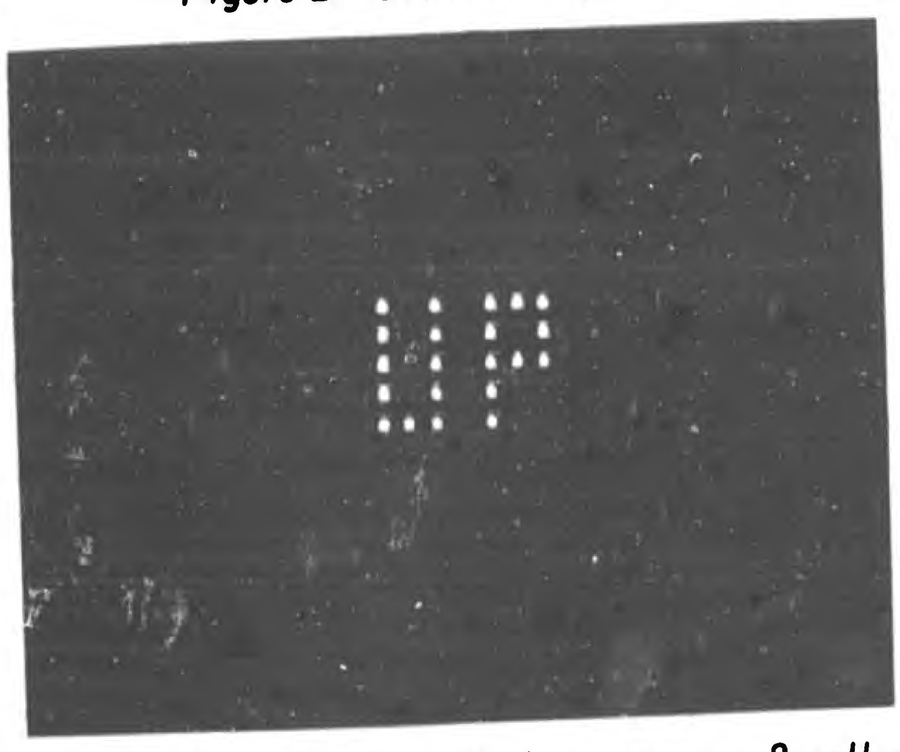

Figure 3. Appearance of characters on 8-cell x 8-cell plasma display panel.

TUNABLE BAND-PASS FILTER USING HIGH-DIELECTRIC-CONSTANT CRYSTALS

A new type of tunable band-pass filter with insertion losses of less than 2 db and with an output spectrum of only a few percent of the center frequency has been demonstrated by James C. Sethares and Martin R. Stiglitz of AFCRL. (1) The narrow band-pass filters can be constructed for any desired frequency from 1 to 12 GHz and for either fixed-frequency or tunable operation.

The basic element of the new filter is a low-loss crystal having a high dielectric constant. Such crystals--rutile and strontium titanate are examples--can be made to resonate at specified microwave frequencies when subjected to an rf field of proper frequency and configuration. When the crystal is placed in a modified waveguide, stripline, or other transmission line structure, it acts as a band-pass filter. That, in essence, is the principle of the new filter.

The band-pass filter technique was demonstrated at AFCRL by using a waveguide. The crystal (dielectric resonator) is cut in disc form and can be mounted on a small Teflon or polystyrene post. An iris consisting of a thin sheet of conducting material with a center opening is inserted as a partition inside the waveguide. The resonating disc is placed in the iris so that it protrudes on either side as shown in Figure 1. When the waveguide is operated above cutoff, the apparatus serves as a band-pass filter.

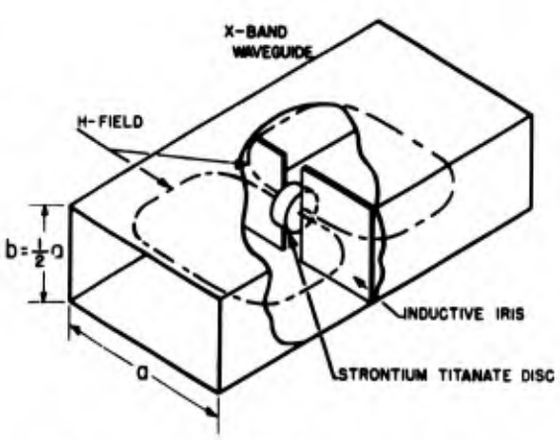

Figure 1. Tunable band-pass filter.

Different center frequencies are obtained by using crystals with different dielectric constants, and by changing the geometry of the crystal resonator itself. (2) However, any given filter can be tuned over a relatively narrower spectrum, either mechanically or magnetically. Mechanical tuning involves mounting two disc resonators inside the waveguide in such a way that they can be brought into contact with each other or moved apart laterally. (3) Separating the resonators results in an increase of the resonator frequency. Tuning ranges of 20 percent of the center frequency have been achieved by this method.

Magnetic tuning is achieved by placing ferrimagnetic materials in the vicinity of the dielectric resonator. Tuning is achieved by magnetizing the ferrimagnetic material with an external magnetic field. Switching speeds--that is, speeds of switching the band-pass center frequency from one value to another--of less than a microsecond are possible. (4) Tuning ranges of more than 15 percent at X-band have been achieved without degradation of the filter response.

Crystals having high dielectric constants are unfortunately very temperature-sensitive. This has limited their application to situations with low input powers and constant ambient temperatures. However, by placing the dielectric resonators in boron nitride, which conducts the heat to the waveguide walls, power-handling capabilities can be extended to several hundred milliwatts. (5) Sethares and Stiglitz have also used a new ceramic temperature-compensating material developed by the American Lava Corporation (AL Si Mag No. 96). Resonators made of this material can operate under relative temperature rises as high as 30° F without

noticeable change in resonant frequency. This allows medium- and high-power application of these dielectric resonator filters.

Filters of this new type would be rugged and compact and would find many military and commercial uses. Band-pass filters are common components in radio equipments and in many signal-processing instruments.

electronics

WHISTLERS AND THE PLASMAPAUSE

One of the significant discoveries of environmental electronics research is the abrupt decrease of electron density at an altitude of about 3 earth radii. This discovery required the diagnostic techniques of whistlers as developed by Dr. R. Helliwell of Stanford University, under contract to AFOSR. The alteration in density occurs in the relatively short distance of about 0.15 earth radius, and the transition region is termed the plasmapause. This implies the existence of a 3-dimensional boundary (plasmapause) that extends around the earth in the near-space plasma called the magnetosphere. This doughnut-like shell separates a dense (100 electrons per cubic centimeter) inner region from a tenuous (1 electron per cubic centimeter) outer region. The presence of the plasmapause was a complete surprise to the scientific community, since no previous theory predicted its existence. Satellite experiments have since confirmed its existence. A model of the magnetosphere is shown in Figure 1.

Measurements have shown that the plasmapause is stable for approximately 18 hours per day, and that during the nocturnal cycle there is a rapid radial variation and less precise definition. This effect is called "breathing." Data to date verify plasmapause breathing, and also indicate that the plasmapause corotates with the earth.

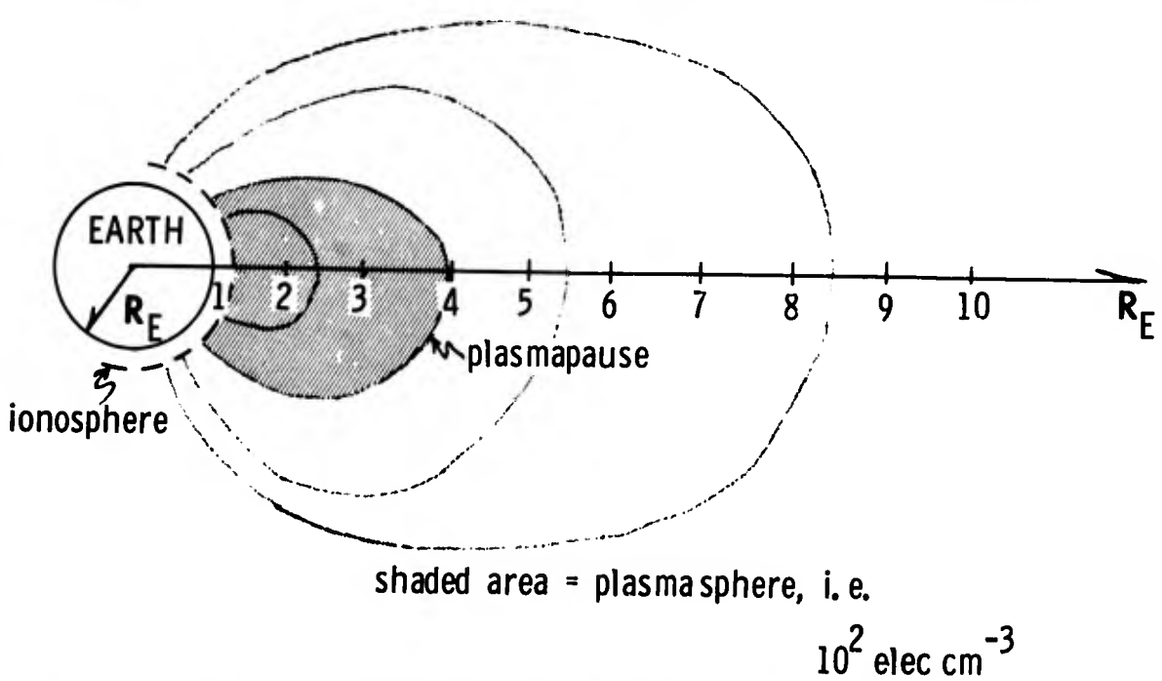

Figure 1. Model of the magnetosphere. The shaded area represents the plasmasphere, with a density of 100 electrons per cubic centimeter.

Recent efforts by Helliwell and his staff involve the use of whistlers to detect magnetospheric motions. No experimental method exists, other than whistlers, to probe these thermal-ionization motions. Whistler theory predicts radial motion of the entire magnetosphere, dependent upon the day-night cycle of the earth and large-scale solar electric fields. Data indicate that there is a perturbation of the magnetosphere on the side of the earth opposite the sun. The effect is something like the immediate tail of a comet and may be caused by solar winds. Studies are being extended to formulate a wave-particle theory to explain magnetospheric VLF propagation and amplification.

Air Force interest in the aerospace environment motivates the development of diagnostic tools such as whistler research techniques. At present, whistlers are our only accurate method for remote near-space investigation.

electronics

OPTICAL EXCITATION WITH LOW-ENERGY IONS

One of the most significant advances in physical electronics in the Joint Services Electronics Program has been the observation of radiation from gases as a result of low-energy ion bombardment. For the last 50 years, scientists have generally believed that virtually all of the light produced by a plasma discharge in a gas resulted from the effects of free electrons on gas molecules. It was supposed that the gas molecules were excited to higher-energy states by collisions with the free electrons, and that the molecules then gave up this energy in the form of light.

It has now been shown by Drs. R. Novick, M. Lipeles and N. Tolk of the Columbia Radiation Laboratory, Columbia University, that low-energy ions have a similar excitation effect on gas molecules and thus can also bring about the emission of light. In the experiments, streams of monoenergetic helium ions with energies as low as five volts were injected into chambers filled with various gases. Production of light under these circumstances demonstrated that gas molecules were optically excited by the ions. Previous studies of optical excitation by ion impact did not reveal the low-energy light-production effects.

The dependence of the amount of excitation on the kinetic energy of the helium ion shows unexpected features down to the lowest energies studied. For example, there is a sharp peak at 10 eV for the production of ultraviolet photons in xenon. A detailed theoretical explanation of these phenomena cannot be accomplished in even the simplest collision problem.

Aside from the insight that these collision processes provide concerning the mechanics of fundamental molecular processes, the observed results are of considerable interest in other branches of science and in certain technological fields. For example, charge exchange with simultaneous excitation has been suggested as a possible laser-pumping mechanism. In atmospheric physics, a knowledge of ion-atom inelastic collisions is essential for the understanding of energy-transfer processes in the ionosphere as well as of the interaction of the solar wind with planetary atmospheres. These collisions are important in very hot plasmas and may also be responsible for a significant portion of the optical radiation observed from both comets and meteors.

CONTINUOUS MEASUREMENT OF WEIGHT CHANGE DURING HIGH-TEMPERATURE OXIDATION

In order to fill a gap in the experimental techniques for studying the oxidation of space-age materials, a system has been developed by Dr. Henry C. Graham of the Metallurgy and Ceramics Laboratory, ARL, to make continuous weight-change measurements at the desired temperatures and in the desired environment.

The two principal requirements met by this system are (1) that the weight change be measurable continuously with sufficient sensitivity, and (2) that the sample be in an oxidizing atmosphere at temperatures as high as 2,400°C. The first requirement is satisfied by using a microbalance which has a capacity of 100 grams and a sensitivity of 2 milligrams. The second requirement, as would be expected, generates many experimental problems. The experimental facility that has been developed uses yttria-stabilized zirconia rings as the inductively heated furnace which is packed in coarse-grained zirconia powder. It was necessary to use a susceptor since direct inductive coupling to the sample resulted in a large force (as high as 1 gram) being superimposed on the true weight change. This and the many other experimental problems associated with this type of facility have been discussed in detail in a published paper. (1)

Zirconium carbide (ZrC) is representative of the type of material the system was de-

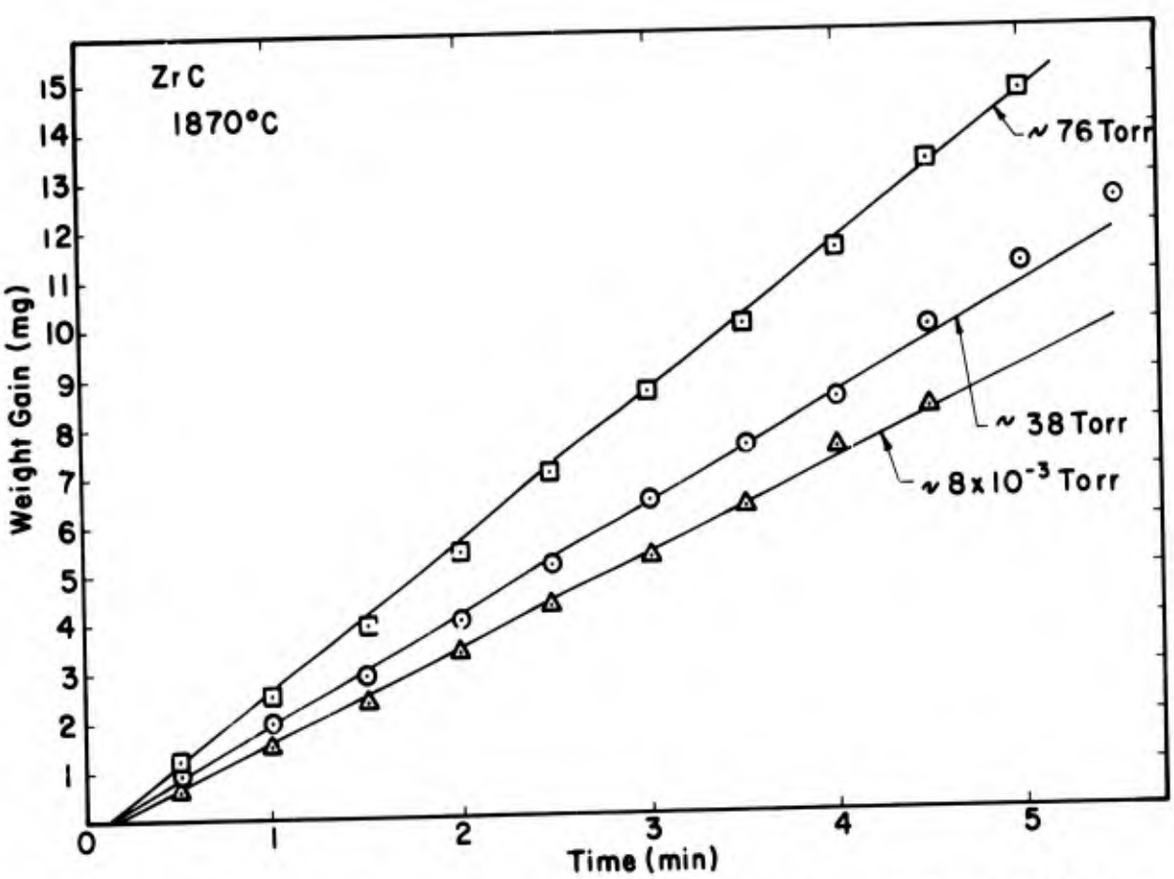

Figure 1. Weight change with time in zirconium-carbide samples during oxidation at 1,870°C, as a function of oxygen pressure.

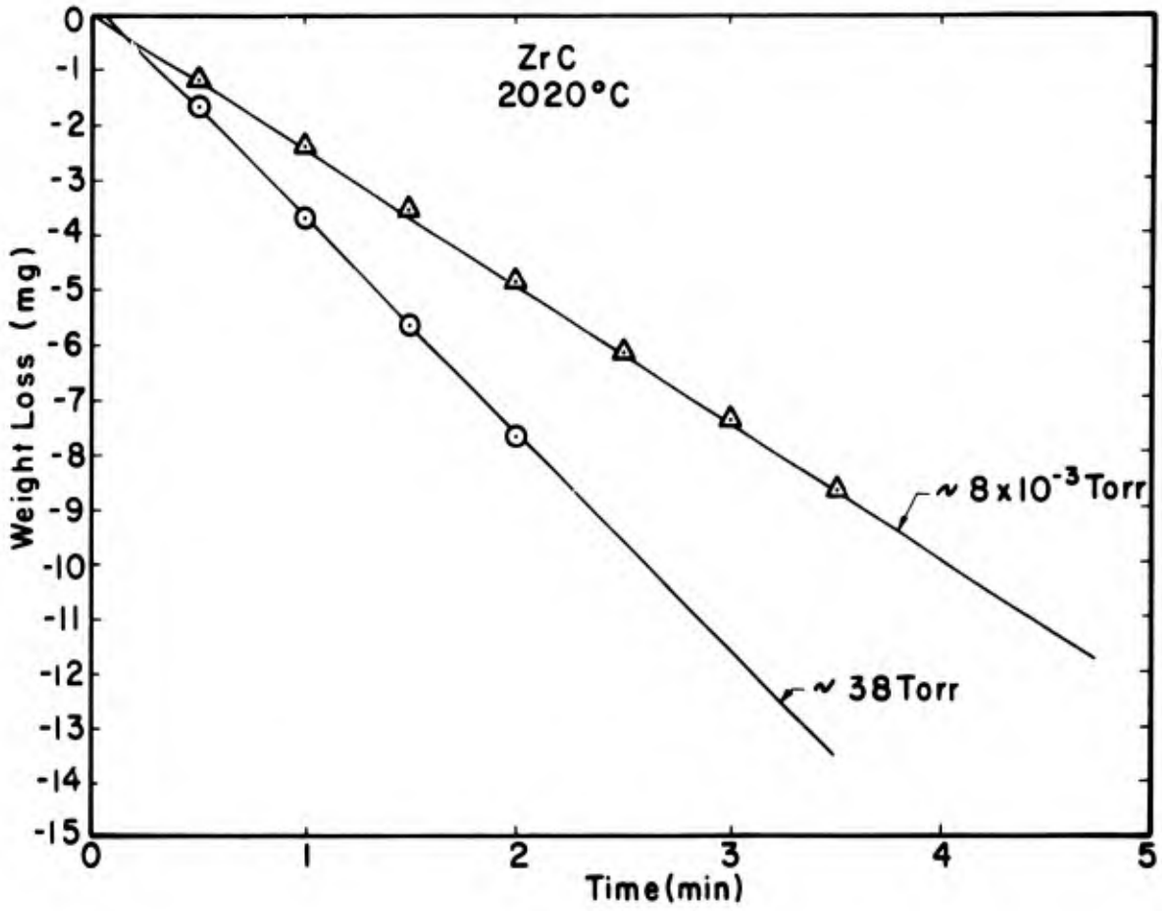

Figure 2. Weight change with time in zirconium-carbide samples during oxidation at 2,020°C, as a function of oxygen pressure.

signed to study. Weight-changes in this material have been measured. (Figs. 1 and 2.) Data taken at 1,870°C indicate the results expected for ZrC, i. e., that there is a weight gain with time as zirconium oxide is formed and remains on the surface of the carbide. In addition, the rate of weight gain shows the expected increase with an increase in oxygen pressure. The results obtained at a higher temperature were unexpected, but can be explained quite reasonably. A probable explanation for the weight loss occurring at 2,020°C is that the oxide is now evaporating as it is being formed. Considerably more data are needed before any definite conclusions can be reached. However, the drastic change observed in the oxidation behavior of ZrC at different temperatures points out quite clearly the advantages of a continuous weighing technique over the recession measurement technique generally used in oxidation studies on these materials.

mechanics

RAREFIED GAS DYNAMICS

Military technological interest in rarefied gas dynamics is currently at a high level because of the increasing number of weapon systems whose operational use requires flight within zones in the upper atmosphere where air does not behave as the familiar continuum encountered on the ground. The topic derives significance not only from the direct application to these systems, but also from the detection, communication, and countermeasure problems associated with possession of such weapon systems, both by ourselves

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and by potential enemies.

The tools of progress in rarefied gas dynamics are statistical mechanics and the kinetic theory of gases, coupled with the systematic development of knowledge of the interaction of gas molecules with solid surfaces. Of these, knowledge of the gas-surface interaction is in the more primitive stage of development and, until recently, has defied all efforts to bring it into a satisfactory state. The chief obstacle to progress has been the difficulty of obtaining reliable experimental information about the details of such interactions.

Two kinds of experiments form the chief methods of obtaining this information. They are thermal accommodation coefficient measurements made by measuring the energy given to the gas by heated wires, and scattering measurements obtained by placing suitable target surfaces into a molecular beam. Results obtained by different experimenters have usually failed to agree, and there has been little point in constructing theoretical models.

This situation has changed for the better in large measure because of research supported during the past few years by the Mechanics Division, Directorate of Engineering Sciences, AFOSR. Professor Lloyd Thomas at the University of Missouri has succeeded in making accurate thermal accommodation coefficient measurements by taking meticulous care to avoid surface contamination and gas contamination. The effect of the ratio of masses of gas and surface atoms, and the effect of adsorbed layers of gas on the surface are now clearly discernible from his measurements.

Mr. Joe N. Smith, Jr., and Dr. Howard Saltsburg, both of the General Atomic Division,* General Dynamics Corporation, have made molecular-beam scattering measurements of hydrogen, deuterium, and the rare gases from clean, single-crystal surfaces of gold and silver targets. Their measurements demonstrate such effects as the specular reflection of particles; nonspecular but noncosine law scattering of particles both in and out of the plane of incidence of the beam; effects of surface contamination; effects of beam and target temperature; effects of target crystal structure (i.e., polycrystalline or single crystal); and, with hydrogen and deuterium, the effect of coupling with the rotational motion of these molecules.

Professors Leon Trilling and Harold Wachman of the Massachusetts Institute of Technology have been successfully developing theoretical models which agree with the growing new body of experimental facts, as well as making molecular-beam scattering measurements not only of the spatial distribution of molecules scattered from a target, but also of the velocity distribution of the particles scattered in a given direction.

*Now Gulf General Atomic.

mechanics

A HIGH-REYNOLDS-NUMBER, HIGH-MACH-NUMBER HYPERSONIC TEST FACILITY

The Air Force research and development program is continually seeking aerodynamic design data on advanced aerospace systems. Because of their size and flight altitudes, maneuverable re-entry vehicles will have turbulent boundary layers which influence heat transfer and aerodynamic characteristics. A high-Reynolds-number facility most closely simulates the boundary-layer conditions that these vehicles would experience. A novel concept for such a high-Reynolds-number, high-Mach-number hypersonic facility is presently being explored by Dr. Antonio Ferri at New York University, under ARL contract. The value of this approach is that high-Reynolds-number flows can be obtained with a flow-duration time sufficient to permit boundary-layer studies. High-Reynolds-number flows may already be obtained with shock tunnels, but the flow time, which is of the order of microseconds, is too short to permit detailed boundary-layer investiga-

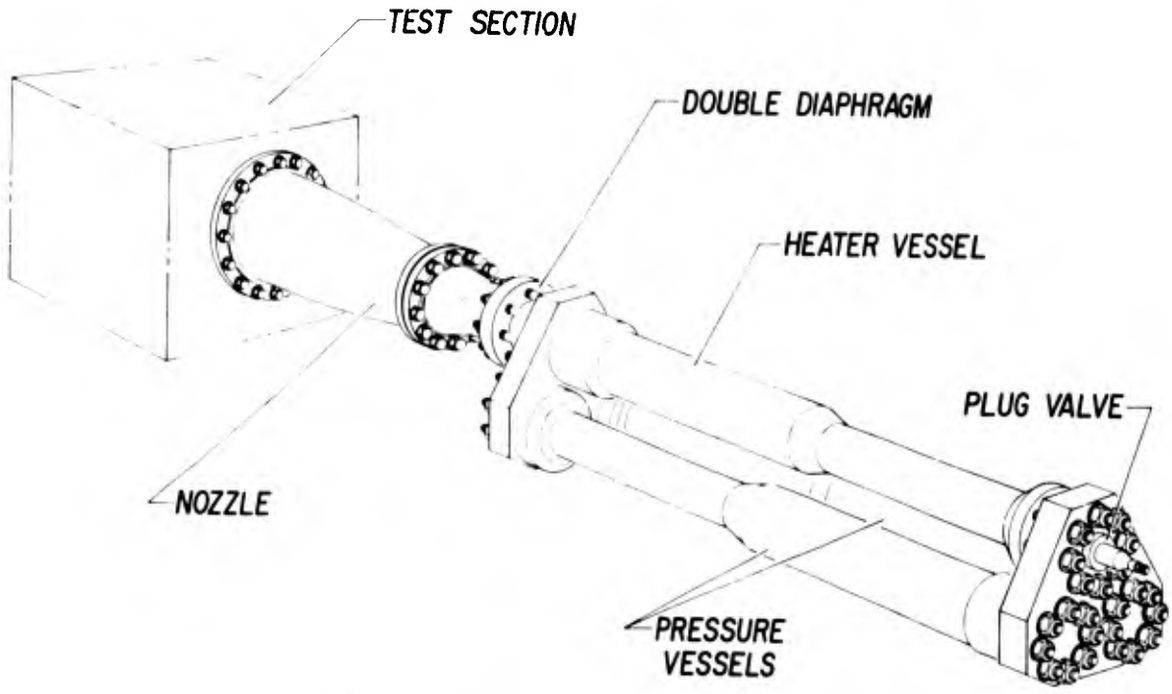

Figure 1. High-Reynolds-number hypersonic facility.

tions. To achieve long-duration, high-Reynolds-number flows at Mach 12 by conventional means would require a facility of tremendous physical dimensions and enormous development costs. The present facility at New York University (Fig. 1) can achieve high-Reynolds-number flows at Mach 14 with flow durations on the order of seconds by using extreme pressures in a mechanically unique fashion. In addition, this facility is no larger than conventional ground test facilities and is limited in cost.

The NYU high-Reynolds-number facility consists of 3 large steel tubes, 2 of which are interconnected to feed the third. The third tube is directly connected to the hypersonic nozzle and test section. The tubes are initially pressurized to about 20,000 psi, and an electric heater located in the third tube raises the temperature above the condensation limits and the pressure to about 30,000 psi under constant-volume conditions. Flow is initiated by bursting diaphragms, and a useful test time of approximately 4 seconds is obtained. The prototype facility is completed. Actual tests of this facility have shown that high-Reynolds-number flows at Mach 14 with 4-second flow duration can be achieved at pressures as low as 12,000 psi. Work is presently continuing to improve the air heater system in order to push the test facility to higher pressures and longer flow times. Interest in constructing similar facilities based on this concept has been shown by NASA and the United States Navy.

mechanics

PROPERTIES OF FLOWING PLASMAS

High-temperature plasma properties and analytical techniques for utilizing these data are needed for a number of Air Force applications such as hypervelocity-wind-tunnel and materials testing, heat-shield design, and various aspects of space propulsion. In addition, interest has increased in radiation sources for various military and scientific applications, e. g., battlefield illumination, solar simulation, aerodynamic heat-load simulation, and inducing temporary blindness. A rational approach to the design of these

sources, calculating energy transport between plasmas and their environment, and interpreting empirical data requires a knowledge of basic plasma properties for use in thermodynamic and transport equations. However, data on these properties are often unavailable or, when available, may be of questionable validity. Thus, a great deal of additional data is required.

In order to help meet these needs, Mr. P. W. Schreiber is studying high-temperature plasma flows at ARL. The basic purpose of this study is to measure transport properties (such as electrical and thermal conductivity, specific radiation, and viscosity) of flowing plasmas in order to determine the flow parameters for which equilibrium thermodynamics and single-fluid transport equations are applicable. Plasma instabilities and turbulence are to be studied and related to plasma parameters. Also, it is anticipated that nonequilibrium flows will be investigated relative to energy transport and radiation amplification.

At present, data are obtained in a high-power (1 megawatt) pulsed discharge in an axial flow field at atmospheric pressure. Measurements at higher pressures are planned for the future. Because of the high power level, large discharge diameters may be obtained. Thus, probes as well as optical methods may be employed to diagnose the plasma. Measurements include temperature profiles, total radiation, current density, voltage gradient, plasma pressure drop, mass flow rate, etc. These data may be reduced to determine the transport properties of plasmas for stable laminar flow, and to determine changes in these properties due to turbulence, instabilities, or nonequilibrium conditions. In addition, the measurements serve as a standard set of data to test the ability of various analytical techniques (including their assumptions) to predict the various profiles in flowing plasmas as well as to estimate energy transport to the plasma environment.

Concurrently with the experimental program, analytical methods are being investigated and developed to reduce basic data to transport properties and to analyze various plasma configurations and flow fields. The absorption of radiation, nonequilibrium conditions, plasma instabilities, plasma turbulence, and nonaxial flow fields present difficult analytical problems.

Although the acquisition of data on the properties of plasmas and the development of analytical programs to use these data are laborious research objectives, their direct application to many Air Force and scientific problems can result in considerable savings in time and development funds.

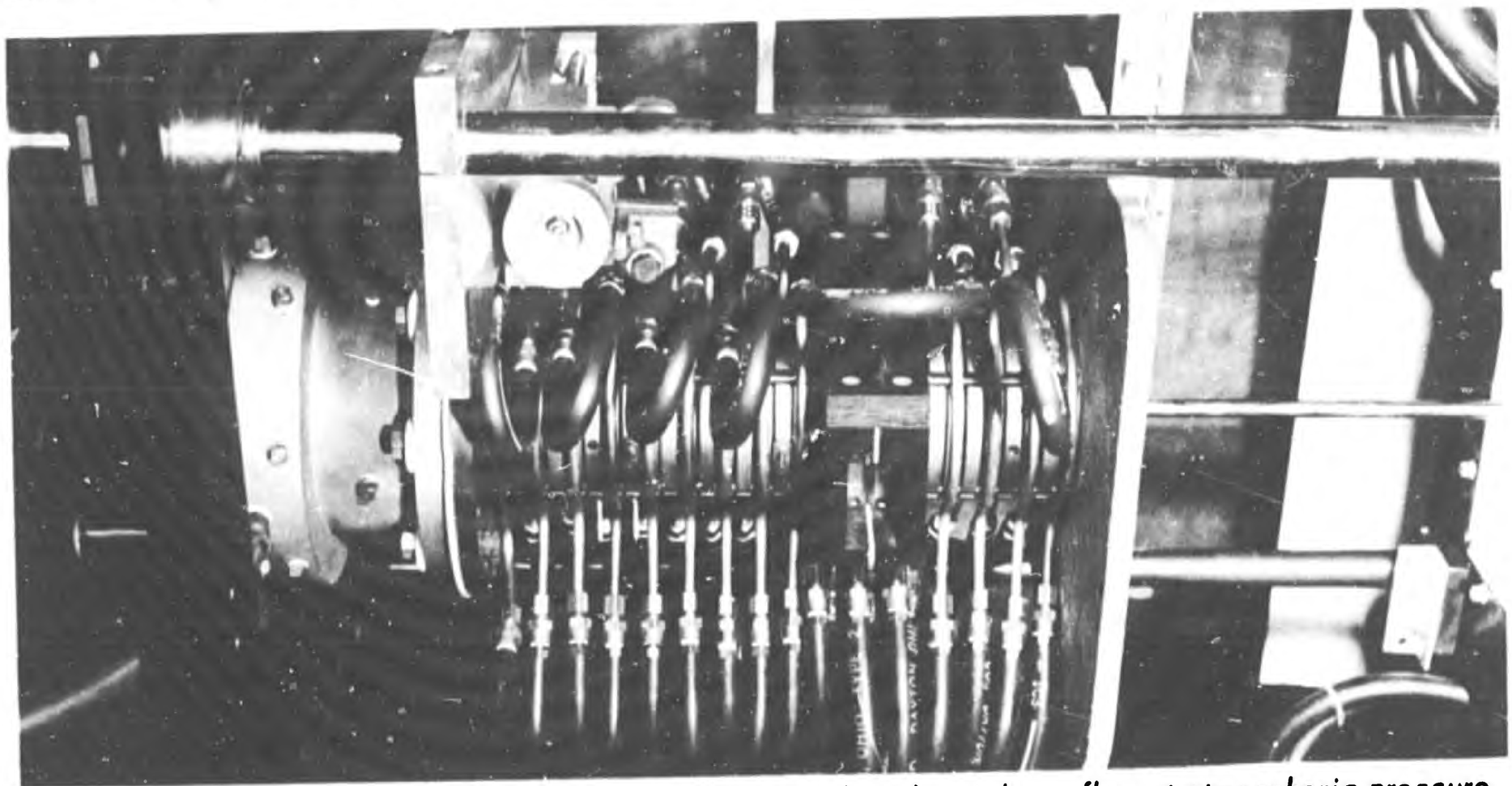

Figure 1. One-megawatt pulsed discharge arc operated with axial gas flow at atmospheric pressure.

NONDESTRUCTIVE EVALUATION OF METAL FATIGUE

A metal structure subjected to an alternating or fluctuating stress can develop a minute localized crack which spreads over the cross section of the structure until it is completely fractured. This type of fracture, called a fatigue failure, occurs at stresses much lower than that required to cause fracture on a single application of load. An overwhelming number of all service failures due to mechanical causes are due to metal fatigue.

The Southwest Research Institute, under AFOSR sponsorship, has developed a number of significantly improved nondestructive means of detecting early fatigue damage in metals. These include a magnetic perturbation technique which is highly sensitive to the localized stresses associated with discrete defects and fatigue cracks in ferromagnetic materials, and an electric-current injection method which is sensitive to the very early stages of crack nucleation and propagation in conducting nonferromagnetic metals such as aluminum. Another technique applicable to both ferromagnetic and nonferromagnetic metals is based on the reflection of ultrasonic surface waves from fatigue cracks with physically separated surfaces and is particularly useful as a continuously monitoring device. To a limited extent the experimental results obtained by these different methods have been correlated with each other, with X-ray diffraction studies, and with surface photomicrographs. Fundamental studies in crack initiation and propagation based on these methods are currently in progress.

The fundamental knowledge that will be obtained promises to be of great value in the fracture design of aircraft and aerospace vehicles. However, in the meantime, the instrumentation developed to obtain that knowledge is currently being adapted for testing the spar of the rotor of the Marine CH-46 helicopter for certain manufacturing faults which have been known to result in disastrous failures. Also, using the magnetic perturbation method developed for AFOSR, the Southwest Research Institute has developed a nearly completely automated inspection apparatus for detecting fatigue damage in the main, steel drive gear teeth of the transmission in the SH-3 helicopter used in the Vietnam action. Furthermore, the ultrasonic surface wave techniques which have been so successfully employed in AFOSR work have been adapted for detecting fatigue damage in the compressor blades in the rotor discs of the T-53 helicopter used by the Army in Vietnam.

EFFECT OF MASS TRANSFER ON A WEDGE-INDUCED LAMINAR SEPARATED BOUNDARY LAYER

Of extreme importance in the design of a vehicle capable of flying at hypersonic speeds is an understanding of the problem of hypersonic boundary-layer separation and the associated pressure and heat-transfer characteristics. Separation may affect the performance limits and allowable design configurations by creating undesirable shifts in loads as well as producing increases in local heat-transfer rates.

An experimental investigation has been made by Capt. Karlheinz O. W. Ball of ARL to determine the quantitative effect of suction on a hypersonic, separated boundary layer on a compression-corner model simulating a lift surface followed by a control surface. In practice, the junction between the lift and control surfaces may not be sealed, thereby causing mass transfer to or from the separated region.

The tests were performed in the ARL 20-inch hypersonic wind tunnel at a nominal Mach number of 12. Suction was obtained by means of a spanwise slot of variable width between the lift and control surfaces, allow-

ing controlled natural flow from the upper high-pressure region to the relatively low-pressure region at the base of the lift surface. Surface-pressure measurements at a wall to stagnation temperature ratio of 0.56, and heat-transfer measurements at a wall to stagnation temperature ratio of 0.28 were made for control-surface deflection angles of 0, 5, 10, 15, and 20 degrees.

The extent of separation is shown to be extremely sensitive to suction. Removal of a small percentage of the boundary-layer mass flow is sufficient to collapse the separated flow region for the configuration investigated. The mass transfer required for no separation was derived from integration of the first momentum integral equation, which yielded good agreement with experimental data.

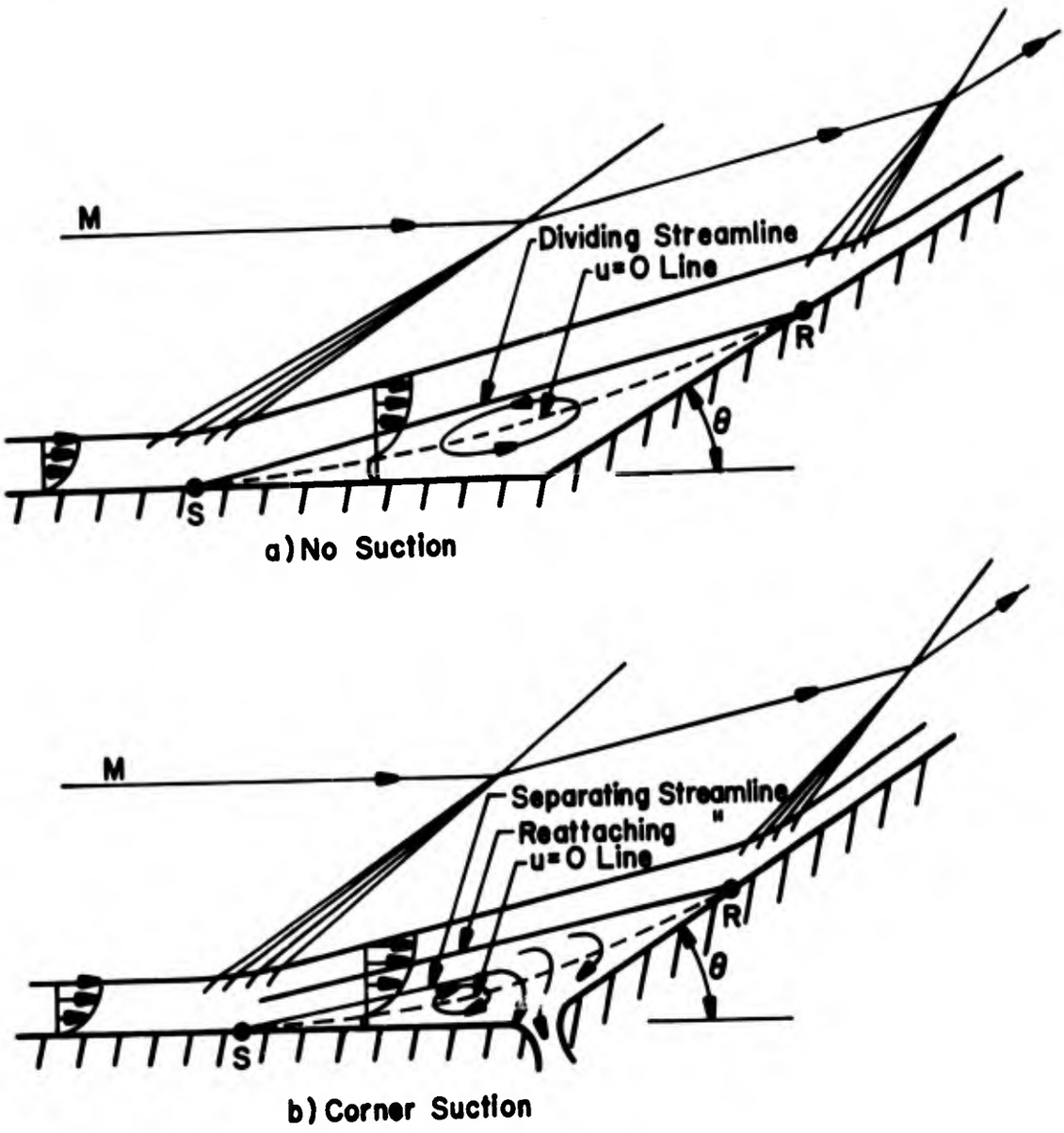

Figure 1. Flow separation in a compression corner with and without suction.

BOUNDARY-LAYER TRANSITION—ROUGHNESS EFFECTS

The fluid which is dragged along by a body moving through a fluid, such as air, is called the boundary layer. Within this boundary layer the velocity changes rapidly from that of the body to that of the fluid outside the boundary layer and thereby produces shearing friction drag on the body as well as friction heat transfer to the body. Another phenomenon of the boundary layer is the sudden change in the thickness and character of the flow along the surface of the body. This change is called transition, and the point at which it occurs is primarily a function of the ratio of the inertial forces to viscous forces

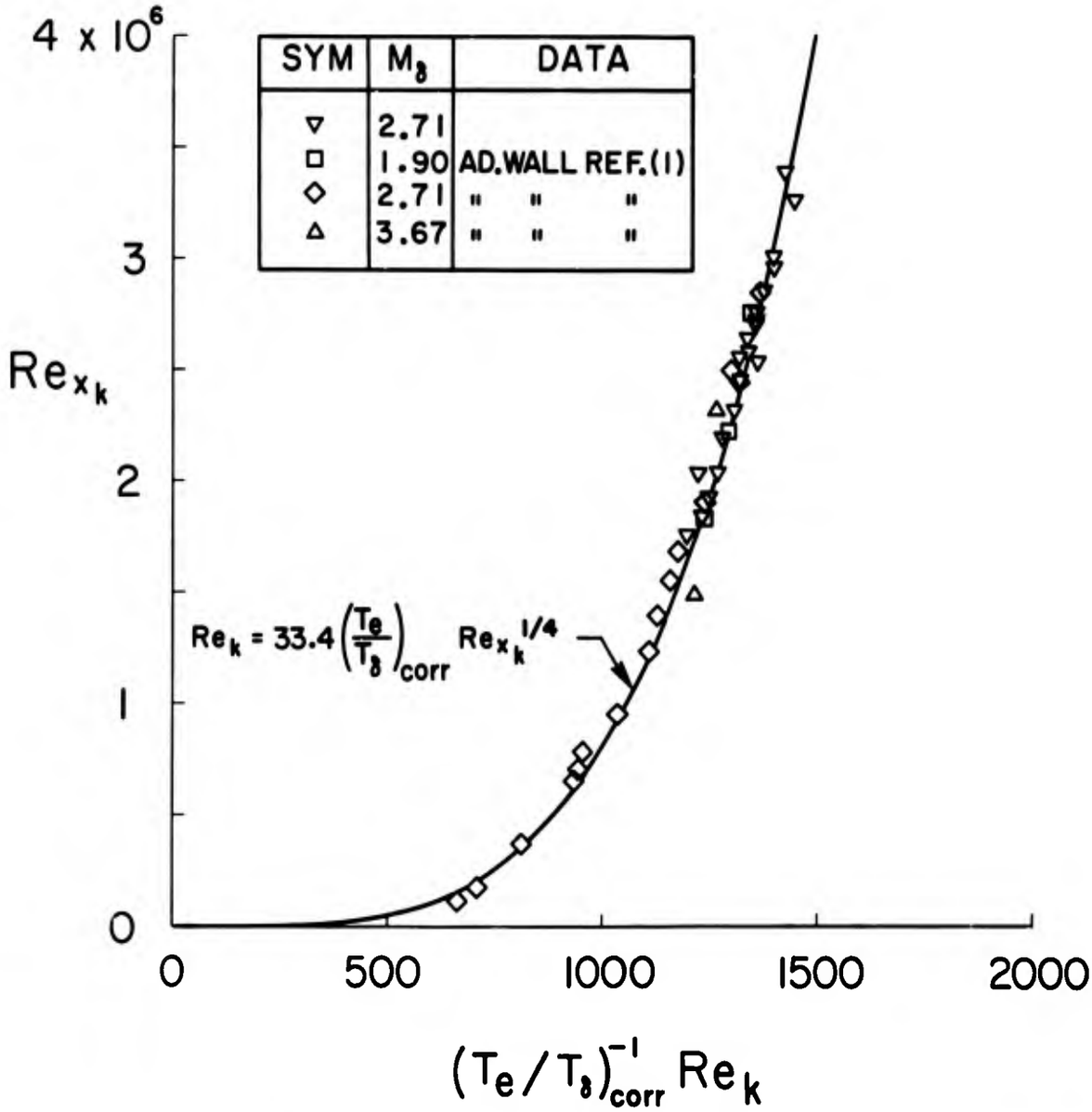

Figure 1. Composite plot of effective transition data, including compressibility and cooling.

within the boundary layer. This ratio is called the Reynolds number. The occurrence of transition results in radical changes in the pressure distribution and the friction drag on the body and heat tranfer to the body. Since it is not practical to build and operate perfectly smooth insulated surfaces, the influence of surface conditions such as roughness and heat transfer must be understood if transition is to be controlled.

The realization of supersonic flight, with its associated compressible boundary layer, has prompted the Air Force Office of Scientific Research to support the basic-research study by Dr. E. R. van Driest of North American Aviation, Inc., into the effects of roughness with heat transfer on transition.

Roughness studies have been conducted in the 12-inch and 20-inch supersonic wind tunnels of the Jet Propulsion Laboratory, California Institute of Technology. The tests were carried out on 10° cones at local Mach numbers 1.90, 2.71, and 3.65, whereas heat-transfer (cooling) studies were conducted at Mach number 2.71 only.

From the data a simple relationship (Fig. 1) was found between the Reynolds number of trip (Re_x) and the Reynolds number of trip position (Re_{x_k}). Also, the difference in Reynolds number between trip and transition position was found to be independent of heat transfer, the difference being a Reynolds number of 0.5×10^6 for a local Mach number of 2.71. Therefore, it was concluded that the trip position-transition interval will still increase with Mach number and is unaffected by heat transfer. This fact should be very significant in considering transition on very-high-speed re-entry craft.

The results of this research have application to vortex generation on wing surfaces, calculation of tolerable roughness to maintain smooth flow, supersonic flow region around missiles, high-speed underwater craft, and wakes of re-entry bodies.

mechanics

HIGH-PRESSURE ARCS

At pressures greater than one atmosphere, the radiation from an electric arc becomes a very important term in its total energy balance. In a noble-gas arc plasma, for example, radiation with an intensity in the 10^3 to 10^5 w/cm^3 range occurs when the plasma temperature is above $10{,}000^{\circ}$K. Thus the power radiated from such an arc approaches the total power input.

This high radiation output at high temperatures and pressures is of interest to the Air Force for a number of reasons. First, high-pressure arcs are potentially useful as high-power illumination sources; second, these arcs show promise as energy sources for re-entry simulation; and third, a negative aspect of this phenomenon is that it causes a number of problems with electrode materials (in such devices as arc heaters) caused by radiation.

Extensive research work has been devoted to determining the temperature-dependent material functions of gases (such as radiation-source strength, electrical conductivity, and heat conductivity) at atmospheric pressure; but virtually nothing is known about the gas properties at high temperatures and pressures. Because of this lack of information, the ARL Thermomechanics Research Laboratory has started a high-pressure-arc program which will be performed in two steps, as follows: (1) A 200-atmosphere (3,000-psi) facility has already been installed and testing has begun; (2) A 1,000-atmosphere (15,000-psi) facility is planned for installation in 1968. Experience gained on the

present facility will be applied to the design and operation of the 1,000-atmosphere system.

In the present facility, Dr. Uwe Bauder is operating a wall-stabilized (cascade) arc in a high-pressure argon environment. This device consists of a series of individually cooled copper discs, and is capable of power levels of 18 kw/cm arc length. Steady-state centerline temperatures of 21,000°K have been achieved using this system with argon at atmospheric pressure. In addition to its very high power density, this arc has nearly perfect cylindrical symmetry and well-defined boundary conditions. This makes it possible to determine the temperature- and pressure-dependent material functions by measuring the radial temperature distribution and integral arc data such as the electrical characteristic (current vs. voltage) and the total radiation. Because the arc becomes absorbing at higher pressures, a considerable analytical effort is necessary to reduce the optical and spectroscopic measurement data.

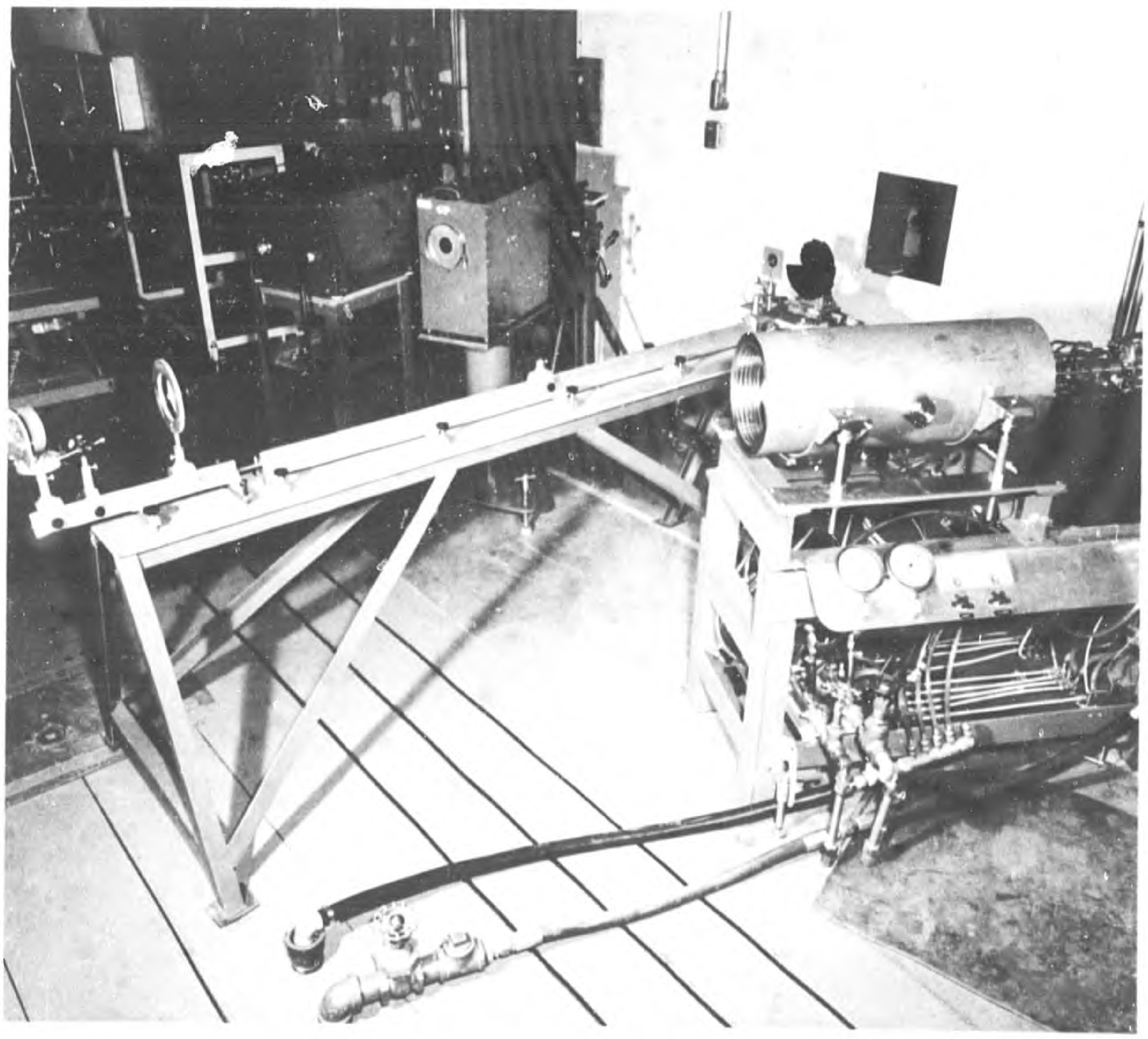

Figure 1. Over-all view of the 200-atmosphere arc facility at ARL. Items shown are: (1) the pressure chamber with the arc assembly slid out; and (2) the optical components and standard arc for spectroscopic temperature measurements and comparisons. (NOTE: The spectrograph itself and the control panels are located behind the wall at top right.)

EXPERIMENTS ON GAS-IONIZING TRANSVERSE SHOCK WAVES

The advent of space travel has recently led to an expanded interest by the Air Force in astrophysics and plasma physics. Laboratory astrophysical research generally involves experimenting with a plasma similar to those generated in the shock waves, boundary layers, and wakes of bodies flying at hypervelocities. Considerable effort has gone into attempting to produce uniform plasmas where all flow parameters are known. One such attempt, under the direction of Dr. George Vlases, is under way at the University of Colorado using an inverse pinch shock tube. In a co-operative effort with Dr. Vlases, Capt. Charles Stebbins of the Aerospace Mechanics Division, FJSRL, and Cadets Duane Clawson and Jeff Hurt of the USAF Academy investigated ionizing shock waves both experimentally and theoretically.

The particular problem studied involved propagating a very fast shock wave (Mach numbers of 50 to 100) into a cold gas which has imbedded in it a magnetic field whose flux lines are perpendicular to the velocity vector of the shock wave. This particular type of shock is called a "transverse ionizing magnetohydrodynamic (MHD) shock wave." It is unusual in that: 1) the plasma, or hot gas behind the wave, can interact with the transverse magnetic field; and 2) the jump conditions across the gas-ionizing shock wave cannot be derived from the conservation equations. This problem was first treated theoretically by Lyubimov and Kulikovskii, who showed that the shock tends to be an ordinary shock for low plasma temperatures, and to an MHD shock (shock propagating into a hot gas) for high plasma temperatures, both cases being uniquely describable by conservation equations alone.

Measurements of the electric field, E, in the plasma, the plasma magnetic field, B, and the shock velocity, u, were made in the inverse pinch device in low-pressure hydrogen, and were integrated through a computerized state equation for equilibrium real-gas effects to provide a theoretical/experimental comparison for the plasma parameters. Cadets Clawson and Hurt programmed the state equation into the digital computer at the USAF Academy. These measurements verified the theoretically predicted low speed limiting behavior and tended toward a smooth transition to the high speed limit. Ohm's law for the uniform plasma, $\vec{E} = -\vec{u} \times \vec{B}$, was experimentally checked and verified. Thus, the inverse pinch/ionizing shock method of plasma production has been verified with a resulting stable, reproducible, and fully understood plasma for laboratory astrophysical applications.

ORGANIC PHOTOVOLTAIC CELLS

Photovoltaic cells composed of organic materials have been prepared and studied for two years by Dr. Aleksandar Golubovic at AFCRL. Since exposure to radiation creates a photovoltage in such cells, they can be used to convert light to electrical energy. The thin-film cells, shown in Figure 1, are fabricated as follows: aluminum electrodes are deposited by high-vacuum sublimation on a pyrex-glass plate; the organic compound and a second electrode (gold) are deposited in turn on the aluminum. Similarly, one can deposit multiorganic layers of different materials.

Two classes of organic materials were examined: (1) photoconductive compounds such as anthracene, tetracene, phthalocyanine, etc.; and (2) nonphotoconducting elec-

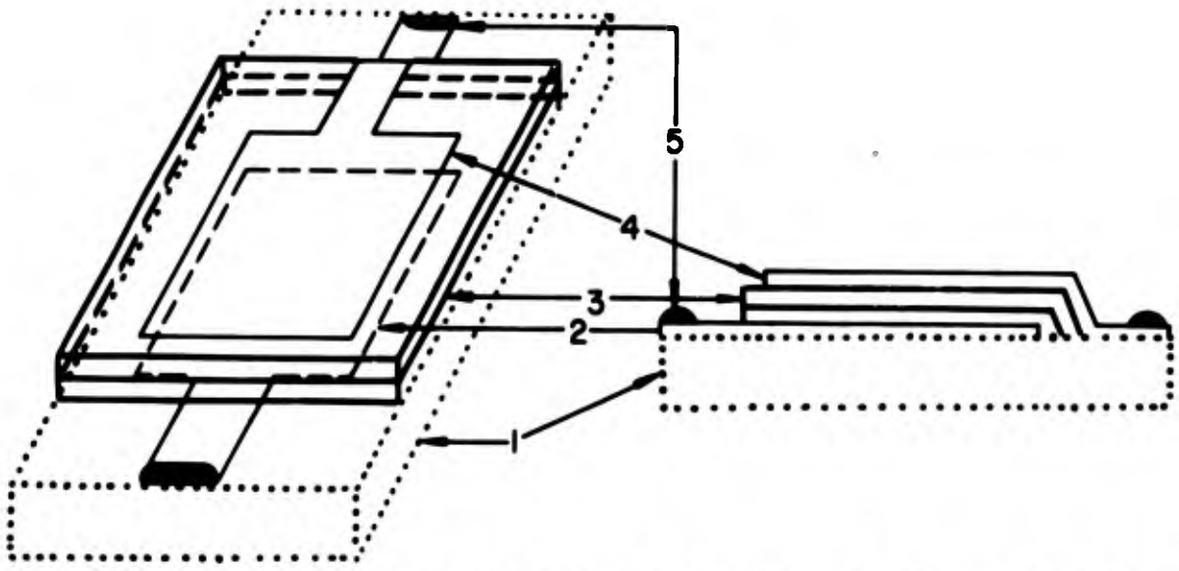

Figure 1. Details of cell construction: (1) glass plate; (2) back electrode, aluminum; (3) single or multiple layer of organic material; (4) front electrode; and (5) silver-paste contact.

tron acceptors such as chloranil. Cells utilizing a single layer of photoconductive material as well as cells containing both classes of materials in double-layer form were produced. More promising results were achieved with the latter. Typical thicknesses of the sublimed organic materials ranged from 1 to 2 microns.

Measurements of photocurrent and photovoltage versus light intensity and wavelength have been performed for the various cells. The polarity of the cells, the relationship between photocurrent and light intensity, and the close connection between the spectral dependence of the photocurrent and the optical absorption spectra of the organic material have been established. However, more data and more intensive analysis are required to understand the basic physics of these prototype devices.

These cells are quite promising since they produce higher power levels than those hitherto achieved with organic materials, even though these levels are well below those of conventional inorganic photovoltaic devices. Such unfavorable properties of organic materials for these devices as softness, high electrical resistance, poor stability at high temperatures or radiation fluxes, can easily be offset for specialized applications by low cost and weight, great flexibility, and structural variety. This inexhaustible variety, in particular, should permit devices to be tailored for specific applications, such as special sensors designed to respond to distinct regions of the spectrum. A search for new materials in conjunction with increased understanding of the phenomenological aspects of photovoltage should ultimately produce practical organic photovoltaic sensors and energy convertors.

energy conversion

ELECTROFLUID-DYNAMIC POWER GENERATION

The prime requirements of high reliability and long lifetime for space and remote-area power systems have resulted in a heavy research emphasis on direct energy conversion, that is, processes which do not employ moving mechanical parts. One such possibility is the conversion of fluid-dynamic energy into electrical energy by electrofluid-dynamic (EFD) generators wherein an electrically insulating fluid transports charges of one

polarity against an electrostatic field. Analogous to conventional Van de Graaff generators, EFD generators produce very high potentials and low current densities. However, with suitable working fluids at high pressure levels, and with appropriate channel and electrode geometries, attractive power densities and conversion efficiencies appear to be feasible. Under the leadership of Dr. Hans J. P. von Ohain and Mr. Maurice O. Lawson, ARL has been conducting research to establish the fundamental working characteristics of EFD processes.

A major limitation of EFD generators is an extremely low total pressure ratio per stage which is incompatible with the pressure-ratio requirement for an efficient conversion cycle from heat into fluid-dynamic energy. To resolve this incompatibility, ARL's research effort is guided by a two-loop concept in which a high-pressure-ratio

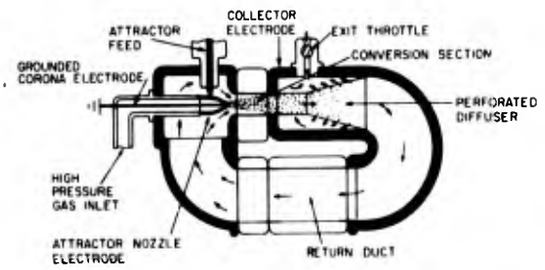

Figure 1. Recirculatory EFD generator (closed-cycle simulation), schematic view.

thermodynamic cycle and a low-pressure-ratio EFD generator are coupled efficiently through an injector process. Although the eventual system is envisioned as employing different working fluids in each loop, present research rigs simulate this system by using pressurized air in both flow loops. (Figure 1)

The capability to seed the gas flow with high charge densities represents the key to

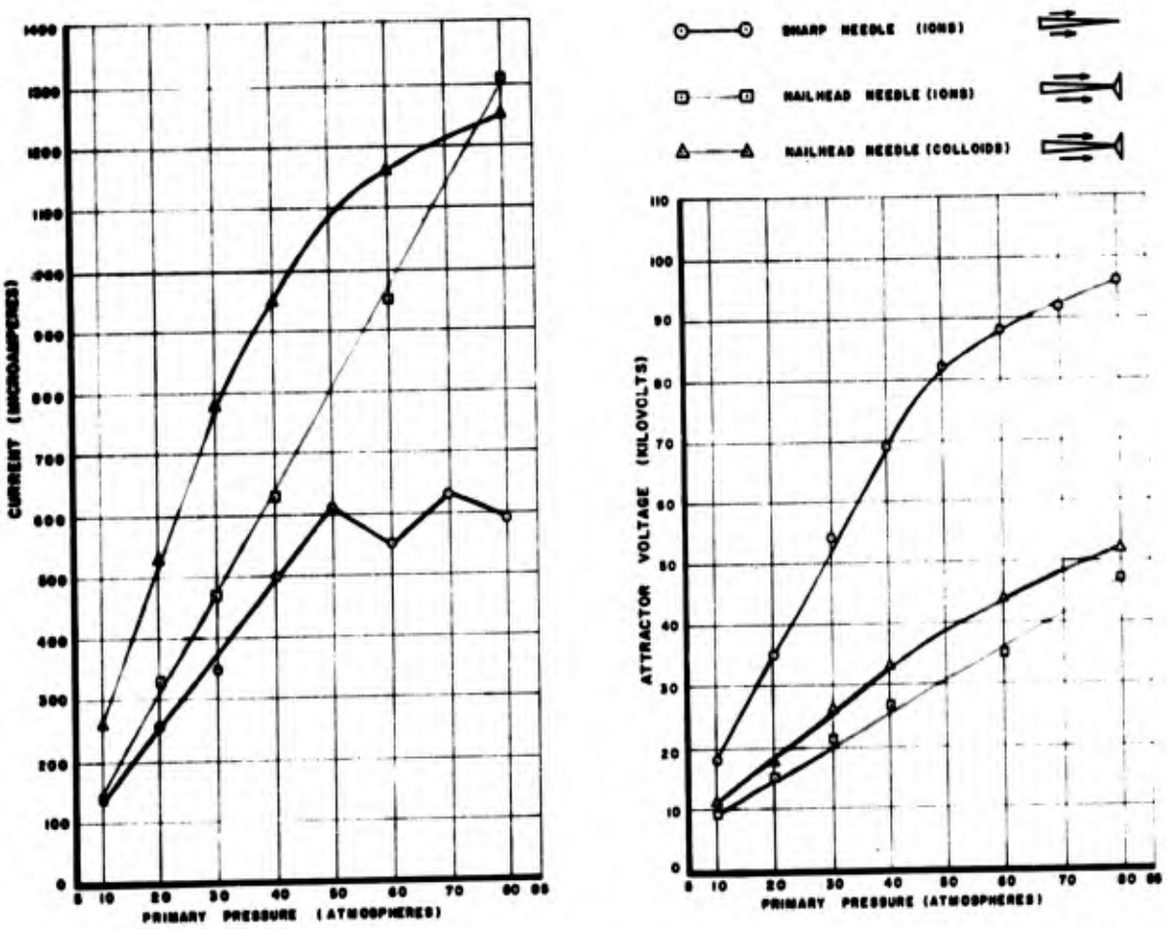

Figure 2. Corona current and voltage versus operating pressure.

successful operation of the ARL concept. Hence, the major portion of the research has been devoted to charge production. A corona discharge from a needle electrode centered axially in a ring-attractor-nozzle electrode has been investigated for the seeding of molecular ions and charged aerosol particles at inlet air stagnation pressure levels up to 80 atmospheres. The aerosol particles have been produced by free condensation upon ions of a small mass fraction of water vapor added to the inlet air. As predicted theoretically, ion currents are found to vary linearly with total pressure level over the range tested, although special "nailhead" needle electrode geometries to establish local low-pressure regimes had to be developed for total pressure levels above 50 atmospheres. For reasons not yet completely understood, charged aerosol currents have been found to vary linearly with pressure level only up to about 40 atmospheres. (Graphs of corona current and voltage plotted against operating pressure are shown in Figure 2.) Size-scaling tests utilizing attractor nozzles of 1/8", 3/16", 1/4", and 5/16" diameters have shown higher performance than expected for the smaller nozzles. A special test rig has been built to extend the test results to nozzle diameters as small as 1/32". The experimental information gained thus far has been incorporated into the design of a "ring-nozzle" assembly which promises for one nozzle that combination of high-charge density and mass flow corresponding to the performance of several hundred small circular nozzles.

Electrical-power experiments accomplished on an early fiberglass-insulated test rig yielded half a kilowatt at 400,000 volts (the practical limitation of the generator). Recently, a second-generation test rig utilizing compressed gas as the insulating material has been fabricated. Operational voltages in excess of a million volts have been demonstrated. Coupled with the expected advances from current production research, power-level experiments with this new rig should extend to several kilowatts.

energy conversion

DETONATION BY SHOCK IN SOLID PROPELLANTS

A large solid-propellant rocket represents a tremendous amount of energy in a metastable state, and this naturally leads to concern that the well in which the system eventually finds itself may not be deep enough to insure peace and tranquility on the firing pad. AFOSR has a continuing program of research on combustion dynamics within which fall specific projects concerning rocket safety--including combustion instability, propellant sensitivity, and the relationship between deflagration and detonation.

In line with this general program, AFOSR sponsors basic research at several educational and research institutions on initiation to detonation in propellants and explosives. At the University of Cambridge, England, Prof. F. P. Bowden directs an investigation of the transition from deflagration to low-velocity detonation in liquids, jels, and solids. The purpose of the Cambridge work is to study the mechanisms by which explosive waves can develop and spread in such systems.

At IIT Research Institute, Mrs. Hyla Napadensky is investigating the mechanism of the initiation of solid propellants by low-speed impact. The objectives are to analyze the processes that occur during propellant deformation, identify regions of energy dissipation, and to observe sites of propellant initiation. Also, at IIT Research Institute, Dr. T. A. Erikson will shortly undertake a study of the nature of sensitivity.

For several years a basic study of the detonation characteristics of low-density granular materials has been directed by Dr. Marjorie W. Evans and Dr. Leslie B. Seely at Stanford Research Institute (SRI). Detailed experimental and analytical studies on the shock sensitivity of ammonium perchlorate (AP), a component of many propellants and a low-powered, insensitive explosive, reveal initiation characteristics that

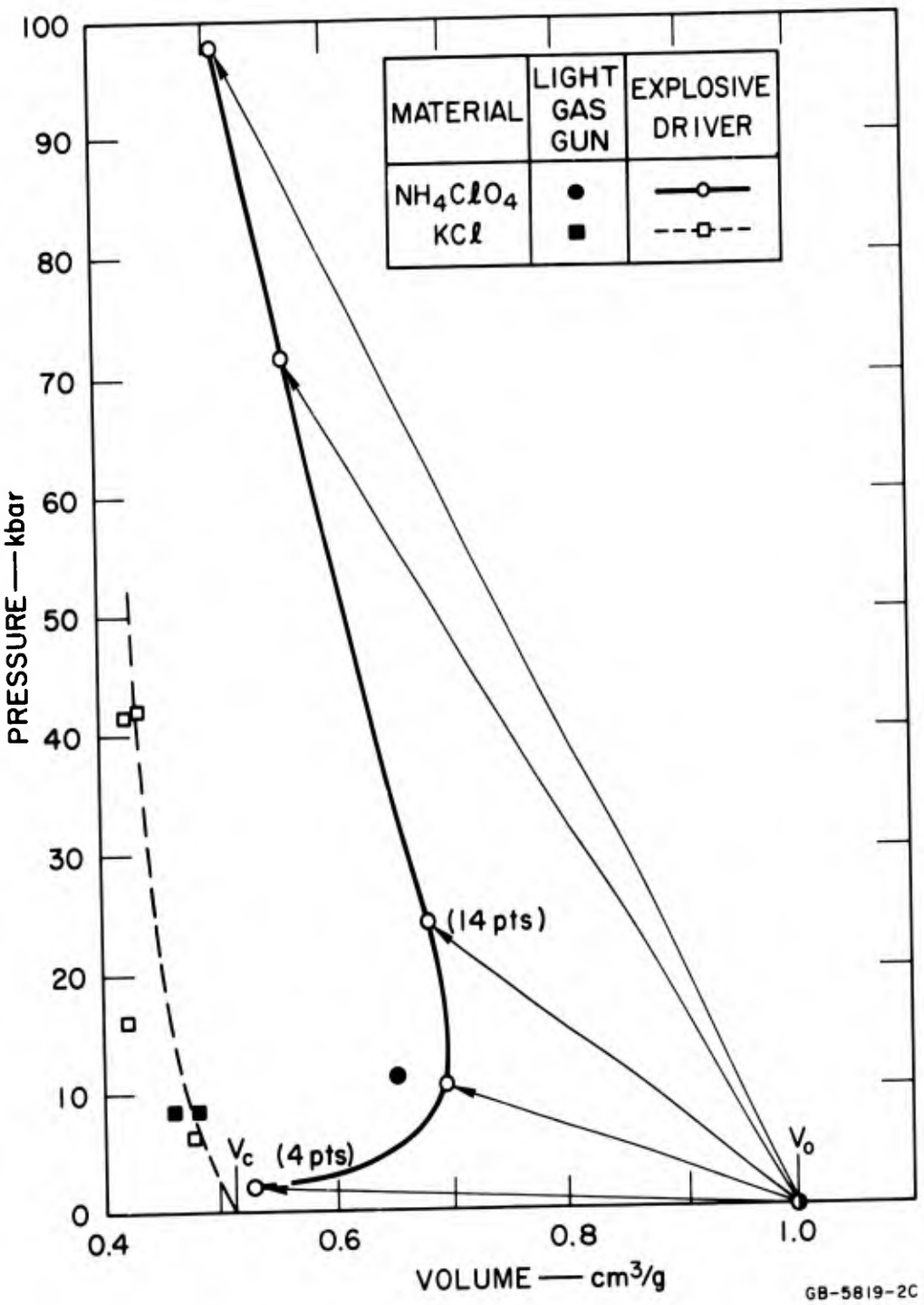

Figure 1. SHOCK COMPRESSION CURVES OF POROUS AMMONIUM PERCHLORATE AND POTASSIUM CHLORIDE. The locus of shocked states for the NH_4ClO_4 has a positive slope for weak shocks, whereas the slope of the KCl curve is everywhere negative. The difference between the two curves in the region from 10 to 40 kilobars is ascribed to chemical reaction in the hot spots at the shock front for NH_4ClO_4, whereas the KCl is inert. Similar results have been obtained for NaCl at the same porosity ($m \simeq 2$).

apply to granular explosives generally and may have important implications for the shock vulnerability of propellants.

A study of the initiation behavior of 13-μ (median particle size) AP has been made at density 1.0 g/cm^3 (porosity m $\simeq$ 2). (1) Shocks from precision high explosives were adjusted to the proper pressure with multilayered attenuator systems. The data are displayed in the pressure-volume plane in Figure 1. Note that in the region below 10 kbar the harder you hit the AP aggregate the bigger it gets! This sort of backwards Hugoniot curve has been noticed by the Russians in inert granular material, but for m $\geq$ 3 and never for m = 2.

The SRI team examined the possibility that this effect was entirely due to heterogeneity, but soon began to suspect it was due to chemical reaction. Two lines of work now make this conclusion more definite. First, check experiments using a light-gas gun instead of an explosive system confirm earlier results. Second, experiments were run on a similar granular material, KCl, in which no chemical reaction could possibly occur. The reactive NH_4ClO_4 shows a dramatic qualitative difference that cannot be explained as a physical difference of the granules or as experimental error. The difference is between curves derived from measurements made on shocks before the transition to detonation. Thus, the indicated chemical reaction exists as soon as the shocks enter the AP aggregate.

Currently, hot spots are being studied and their properties related to the shock-to-detonation transition. Figure 2 shows an image-converter picture of hot spots produced by a 55-kbar shock when it collapses an aggregate of 2-mm KCl grains. At present the spectroscopic properties of the hot spots are under study with photomultiplier-filter combinations. Information on the size and temperature of hot spots is expected to clarify the details of the initiation process.

The SRI work, leading to a clear understanding of initiation processes in low-density granular material, provides a firm scientific basis for the design of safe ignitors, initiators, detonators and other components of explosives. What has been learned about interstitial chemical reactions is useful to those entrusted with safeguarding the viability of the warheads and rocket engines on which our national deterrent capability depends. The over-all effort on detonation, sensitivity and deflagration, and the relationship among these subjects is producing definite progress toward the achievement of Air Force research objectives in the field of combustion dynamics. We are, in fact, gaining the basic understanding necessary to build safe, invulnerable rocket engines and components.

Figure 2. HOT SPOTS IN POROUS POTASSIUM CHLORIDE. This picture was taken with an image converter at an exposure time of 10^{-7} sec on Polaroid film. The shock entered an aggregate of 2-mm KCl grains at settling density from a thoroughly blackened Plexiglas attenuator in which the pressure was about 55 kilobars. The exposure was timed to record the light just as the shock emerged from the surface of the grain bed. The interstitial gas was methane.

ACCURATE THERMAL MEASUREMENTS

One of the most direct connections between purely basic research and engineering application exists in the case of research on thermophysical properties. Accurate data, painstakingly acquired in the academic atmosphere, are almost immediately used by one or another segment of the community concerned with technological advances. Especially is this true in the various aerospace technologies where "estimates" and "overdesigning" are no longer a part of the engineer's stock-in-trade.

OAR support of research on thermophysical properties has three main objectives: (1) the acquisition of reliable and accurate data on the thermodynamic and transport properties of solids, liquids, gases, and plasmas of interest to Air Force technologies; (2) the development of new or improved laboratory techniques for acquiring such data, particularly at higher temperatures; and (3) the obtaining of better auxiliary (e.g., spectroscopic) data, and using them in improved theoretical calculations of thermodynamic properties in temperature ranges not yet susceptible to direct measurement. Some recent events in the second area (measurement techniques) are briefly described here, as examples of the steady, significant progress being made in the whole thermophysical-properties program.

Adding to a long list of previous "firsts" in combustion calorimetry, the Thermodynamics Laboratory of the U.S. Bureau of Mines at Bartlesville, Oklahoma, with AFOSR support, has evolved successful methods for obtaining accurate heats-of-formation of organometallic compounds containing boron or silicon, (1, 2) and organofluorine compounds. (3) By placing aqueous solutions of excess hydrogen fluoride in the rotating calorimeter bomb, W. D. Good was the first to carry out oxidations of these types of compounds to quantitatively characterized final states.

The only apparatus in the world for the measurement of heats-of-reaction by fluorine flame calorimetry is in the laboratory of Dr. G. T. Armstrong at the National Bureau of Standards (NBS). Under the AFOSR-sponsored program at NBS, (4) recent extensive modifications to this apparatus have been made so that F_2O could be used as the oxidizer in the flowing-gas system, and the heat-of-formation of F_2O obtained from precise knowledge of the kind, state, and amount of the products of its reaction with hydrogen.

In another part of the program at NBS, Dr. T. B. Douglas has created the first enthalpy-measuring calorimeter outside Russia capable of reaching 2,800°K. (4) This is a "drop" calorimeter, which permits one to measure the enthalpy change of a sample (solid or liquid) when dropped from a precisely controlled and measured high-temperature environment into one of low temperature. A pulse calorimeter has also very recently been put into use at NBS (5) for even higher temperatures, where data are very much needed. This dynamic method promises to be able to measure precisely the heat capacities of electrical conductors up to their melting points. Planned refinements to increase the speed of the measuring system will make this apparatus unique. Its feasibility has already been proved by measurements on molybdenum and tungsten.

Being assembled at Purdue University is a movie apparatus designed and built by Professor W. Leidenfrost under AFOSR contract. Upon its completion, precise and simultaneous measurements will be made of 9 thermal properties of gases and liquids, from 80° to 900°K, and from a few torr to 500 atmospheres.

DESIGN ANALYSIS OF CROSS-FIELD ACCELERATORS

The successful achievement of useful efficiencies in nonequilibrium electromagnetic cross-field (J x B) devices, both generators and accelerators, has been thwarted by the inability to accurately analyze the plasma and field characteristics of such devices. Purely experimental approaches of a "cut-and-try" nature have met with only limited success in the past, and these failures have not been fully explainable in analytical terms. Several interrelated research efforts being sponsored by AFOSR show considerable promise for breaking this "analysis barrier." The results of these efforts have, in fact, been used in the design analysis of a large cross-field magnetohydrodynamic wind tunnel for the Air Force Systems Command.

The STD Research Corporation of Pasadena, California has developed a mathematical analysis and numerical solution for the many interrelated physical mechanisms that act simultaneously on the flowing plasma to affect both the local and the over-all characteristics of the J x B devices. Ion momentum exchange cross sections and Ohm's-law relationships used in the computation were developed by STD under AFOSR sponsorship. The analysis specifically in-

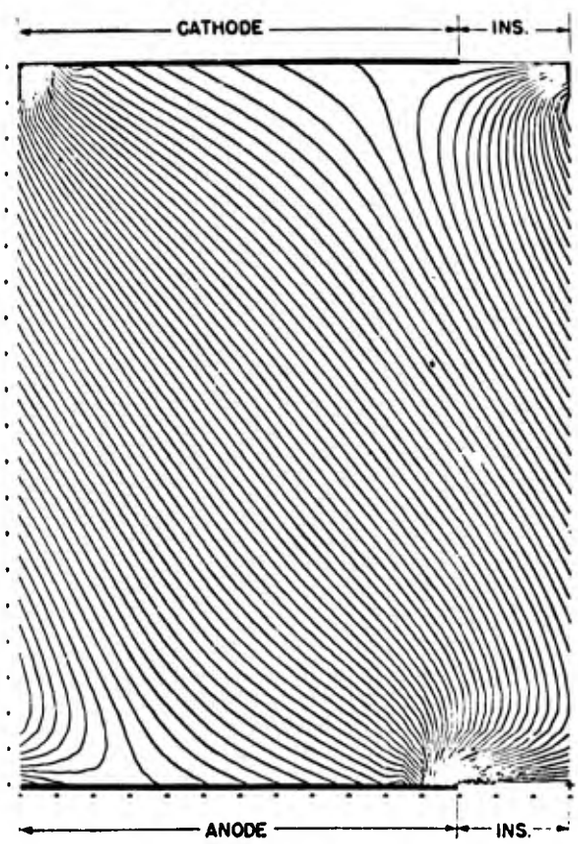

Figure 1. Current streamlines. Uniform gas temperature Tg = 3000°K and gas velocity U = 3000 m/sec. Contour interval 100 A/m.

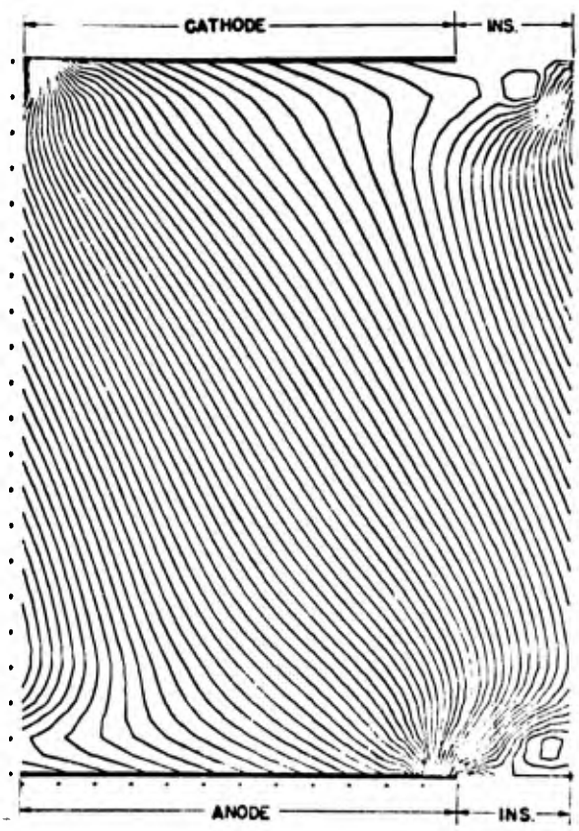

Figure 2. Current streamlines. Boundary layers for the gas temperature (Tg = 1600 at wall, 3050, 3200, 3030, and 3000° K in the core) and for the gas velocity (U = 600 at wall, 2460, 2720, 2880, and 3000 m/sec in the core). Contour interval 100 A/m.

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cludes the spatial distribution and time-dependence of the current density, the internal electric fields, the plasma electron temperature and density distributions and the ohmic heating as local behavior factors. The resultant over-all characteristics described in the analysis include the gross internal resistance, the efficiency, the Hall potential, and the power output of MHD devices.

The technique developed permits the computation and plotting of cross-field device plasma characteristic profiles for both uniform and nonuniform plasma boundary-layer conditions for various gas velocities, compositions, and geometries. Figures 1 and 2 are typical computed profiles resulting from these efforts. By varying the input design parameters, such effects as inter-electrode shorting and subsequent Hall voltage loss may be predicted or explained.

The method used relies heavily on knowledge derived from several current and previously sponsored AFOSR programs--at STD by Dr. G. S. Argyropoulos, at Stanford University by Dr. M. Mitchner, at General Electric's Space Sciences Laboratory by Dr. A. Sherman, and at the Massachusetts Institute of Technology by Dr. J. L. Kerrebrock. Advancement in the knowledge of plasma behavior in such cross-field devices may well result in more realistic models of the electrical behavior of J × B accelerators and generators, permitting more detailed analysis of the effects of non-equilibrium ionization, high Hall parameter, boundary layers, and thermal diffusion.

energy conversion

INERTIAL PARTICLE SEPARATORS

A continuing, in-house ARL study concerning colloidal-core nuclear reactors, under the leadership of Dr. Hans J. P. von Ohain and Lt Col Melvin R. Keller, has indirectly led to significant advancements in the state-of-the-art of inertial particle separators. These devices are designed to remove particulate matter from flowing gases such as dust in the air being ingested by an internal combustion engine. The work has been stimulated by the serious dust-ingestion problem encountered by turbine engines in Vietnam.

Essentially, ARL contributions to the state-of-the-art have consisted of (1) a new "reversed-flow" separator concept similar to that used in conventional "cyclone" separators for industrial flue-gas particle (fly ash) separation; and (2) redefinition and refinement of the significant geometries and flow-energy parameters which must be optimized in order to achieve the required separation efficiency without causing undue power losses. The ARL reversed-flow concept, as illustrated in Figure 1, achieves greater inertial separation capability by producing a core vortex of very angular velocity. The dust-laden air stream entering the separator is given angular momentum

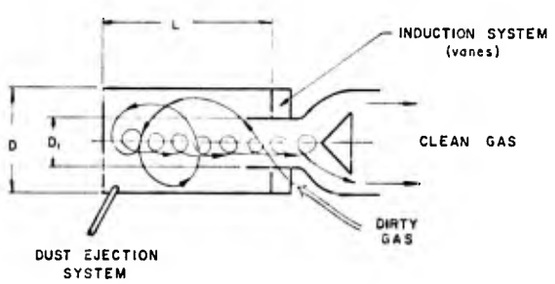

Figure 1. Generalized reverse-flow swirl-chamber dust-separator configuration.

by passing through vanes or an inlet scroll, and then proceeds spirally toward the end of the chamber. At this point the axial flow is reversed and begins to form the core vortex. Dust particles not separated from the outer vortex (and ejected) travel back toward the exhaust tube in the core vortex from which they are likely to be expelled due to the high centrifugal forces. Thus dust particles may be "recycled" several times before either being ejected or passing through the exhaust port. A major portion of the energy removed from the flow to form the vortex is recovered by an appropriate diffuser behind the exhaust port, resulting in a reduced pressure drop across the separator. Unfortunately, the optimum design of a

separator of this type depends on factors peculiar to the particular application, such as the mass flow rate, the particle-size distribution, and some measure of an acceptable balance between power loss and separation efficiency. For example, the size of a separator may be "scaled up" to allow high flow rates, but separation efficiency will decrease. One approach to this problem of achieving higher flow rates without unacceptable drops in separation efficiency is to optimize the separator size on the basis of particle-size distribution and then cluster a sufficient number of the separators to handle the total mass flow. Such a cluster of separators is shown in the photograph (Figure 2).

By a detailed experimental study of these parameters, personnel of the ARL Energetics Research Laboratory were able to determine some general relationships which can serve as guidelines for separator design. The validity of these relationships and of the ARL separator concept has been verified both in the laboratory and in the field. Laboratory experiments have shown, for example, that a mixed test dust could be separated with approximately 90% efficiency from a flow of between 500 and 1,100 cfm by using a cluster of sixteen 5-inch reversed-flow separators. Field tests using a Jeep (see Figure 2) powered by a turbine engine with this flow rate showed that the cluster was capable of achieving even slightly higher efficiencies. More recent tests with a 64-unit cluster have shown separation efficiencies of 97% for the same flow as the 16-unit cluster.

Subsequent improvements and modifications for other applications have shown improved performance. For example, when tested for sea-spray separation from an air stream against commercially available separators, the ARL cluster of forty-six 1-7/8-inch reversed-flow separators was markedly superior and, in some cases, achieved performance superior to the barrier filter which served as a standard of reference. Research is continuing to refine the design approach and to increase the scope of application to such areas as the separation of smokesize particles for air-pollution control.

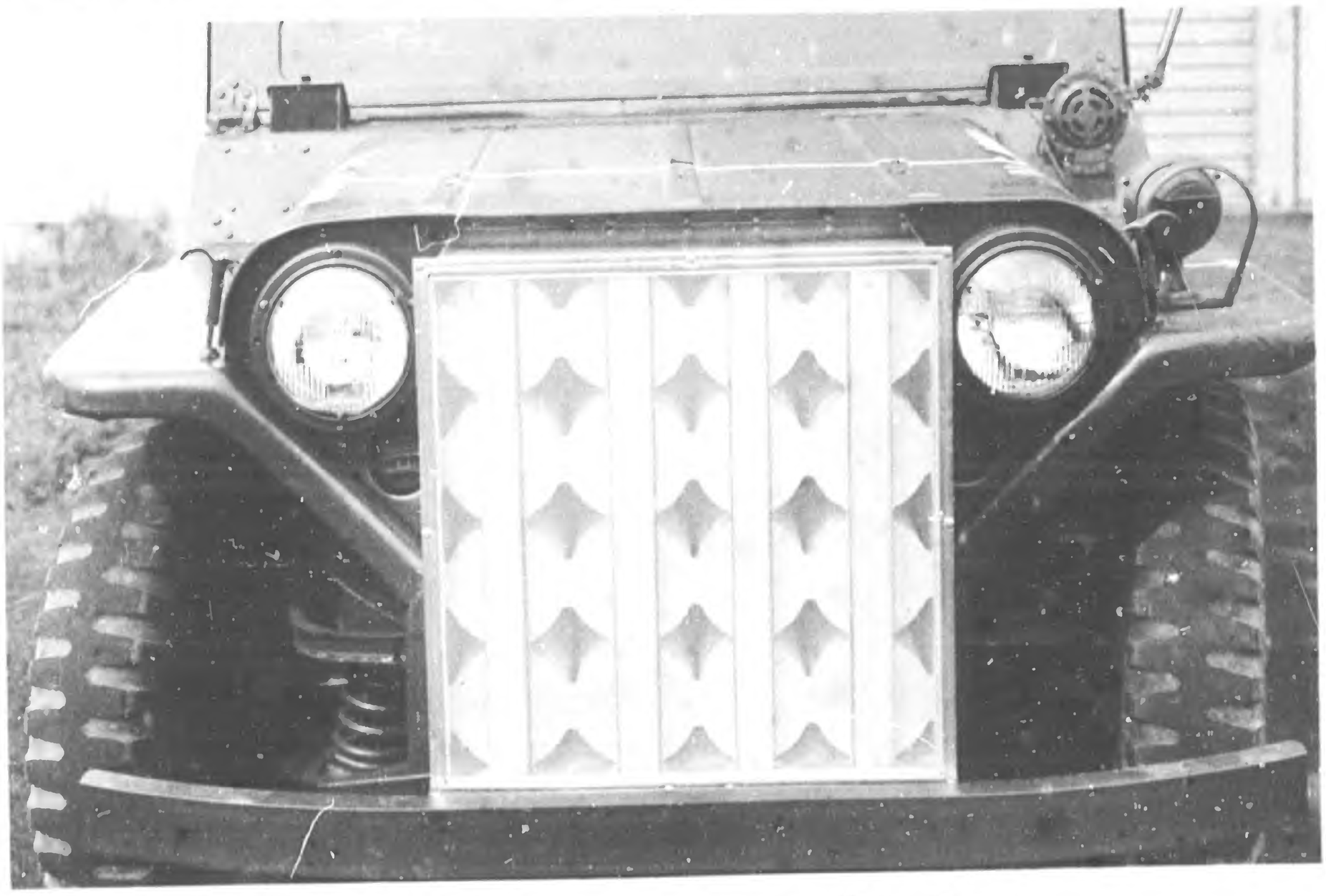

Figure 2. Cluster of separators installed on Jeep.

GEOPHYSICAL STUDY OF DESERT BASINS

In 1962 the Terrestrial Sciences Laboratory, AFCRL, initiated a joint interhouse and contractual study of several desert basins in California and Nevada. The problems in need of answer were how these structural basins formed, how the surface characteristics developed and, because the region is characterized by strong tectonic activity, how stable the region will remain. This region lies astride the northward projection of the East Pacific Rise, a major oceanic ridge for which strong evidence of active sea-floor spreading is accumulating.

Dixie Valley in central Nevada was selected for the most intensive study because of well-documented surface faulting associated with the earthquakes in 1903 and 1954, the availability of repeated geodetic survey data, and the strong likelihood of continued crustal deformation. AFCRL, Stanford University, and the Coast and Geodetic Survey studied the geometrical and temporal relations that are critical to an understanding of the formation of ridges and rifts by every available means, including seismic, gravity, magnetic, geomorphic and geodetic methods.

The results may be summarized as follows:

a. The seismic and gravity data revealed a buried complex depression, bounded by steep faults, containing more than 10,000 cubic feet of unconsolidated sediments. Thus the bedrock relief exceeds 15,000 feet in a distance of less than 10 miles.

b. The shape of the bounding faults of the valley preclude any great horizontal component of motion parallel to the faults. Therefore, as opposed to some supposition, the region appears to be stretching rather than shearing. The mechanism might be similar to that of transform faulting proposed for the oceanic ridges.

c. The geodetic data indicates that, in addition to 5 feet of displacement in the 1954 earthquake, the crust has shifted another foot in the past 10 years. Calculations suggest that some of the earthquake energy was displaced in creating an undetected broad bulge in the crust.

The results, which are generally applicable to a much larger region, can be applied to the selection and design of USAF bases, underground installations and test sites. The thick sedimentary fill permits easy excavation to great depths, but the instability of the region might negate this advantage. The continued deformation of the region would degrade the precision of base lines and orientation control in short order. The ground-water supply is strongly influenced in both space and time by past and present deformation. Geothermal energy sources could be exploited in portions of the area.

WORLDWIDE GRAVITY MEASUREMENTS: PROGRESS REPORT

In September 1962, the International Gravity Commission met in Paris. It was a historic meeting. Its conclusions can be reconstructed somewhat along the following lines: "We've been measuring gravity for all these years, and we still have no way of comparing measurements made at Paris with, for example, those made at Washington or Melbourne. We've used different kinds of instruments, and different analytical methods. Let's now agree on uniform standards, plan a concerted program, and make a fresh start. Let's examine our past work against these standards and see what past results we will preserve, what can be reinterpreted and salvaged, and what we must discard."

Before we look at what's been done during the past four years, let's look at why geodesists have lagged in establishing a worldwide gravity system. Part of the problem

has been the lack of a uniform reference value. When this situation exists, the obvious solution is to arbitrarily designate a common reference value. If there is a "Greenwich" for gravity measurements it is at Potsdam where, as long as 50 years ago, the absolute value of gravity was measured with a pendulum. Modern measurements indicate that the "Potsdam reference" is in error by a negative 11 to 17 milligals. The desired accuracy is about one milligal or less.

The critical problem has been the lack of uniform calibration standards for the calibration of gravimeters, and the lack of a worldwide network of base stations (first-order world gravity net) for the purpose of integrating various local gravity measurements into a single uniform system.

For the establishment of a uniform calibration standard and first-order net, two types of instruments are used in worldwide relative measurements -- relative pendulums and gravimeters. Gravimeters can measure small gravity differences with high accuracy provided the instruments are calibrated on a gravity range (calibration line) where the gravity differences between the stations are known from higher-order surveys. The calibration lines, having a range of 4,000 to 6,000 milligals, are established by high-precision pendulum and gravimeter measurements. Relative pendulums are used to measure large gravity intervals (about 500 milligals) along the line; the number of intermediate stations between the pendulum sites is increased by groups of high-precision gravimeters utilizing special measuring techniques. The obtained relative differences between the calibration stations are then used for the calibration of other gravimeters.

Under the worldwide standardization program that began in September 1962, three standardization or calibration lines were established: (a) the Euro-African line, extending between Hammerfest (Norway) and Cape Town (South Africa); (b) the American line, between Point Barrow (Alaska) and La Paz (Bolivia); and (c) the West Pacific line, from Fairbanks (Alaska) to Melbourne (Australia). The principal stations along the three calibration lines are connected by horizontal (east-west) gravimeter measurements providing a network of base stations called the first-order world gravity net. With the exception of some measurements required for verification along the West Pacific line, the standardization work is completed and the gravimeter measurements for the first-order net are in progress. The completed network will consist of only 36 to 40 first-order stations. Any one of these stations distributed over the continents will provide a relative reference for the regional and, in turn, detailed gravity surveys of each respective area.

The last aspect of the program will involve area surveys, using carefully and uniformly calibrated gravimeters, and base stations established by higher-order surveys. This method, known as terrestrial gravimetry, is feasible over economically well-developed areas. But over inaccessible land areas (mountains, deserts, etc.) and over the oceans, the conventional terrestrial gravimetry is useless. AFCRL has developed and successfully tested in a KC-135 aircraft an airborne gravity-measuring system which is capable of measuring gravity over areas inaccessible to surveys by any other method.

SOLID-EARTH GEOPHYSICS COMPUTER PROGRAMS

To improve the reduction and interpretation of field geophysical data, a novel technique for the semiautomatic interpretation of gravity data has been incorporated into a general-purpose computer program. This permits introduction of several realistic constraints, terrain corrections and multilayered model solutions. In addition, a trend-analysis method appears applicable to both geological and geophysical analysis.

Computers allow rapid interpretation of

seismic and magnetic, as well as gravity data. Analysis can proceed along more realistic lines than afforded by prior methods. Subsurface geological interpretations can be directly applied to preliminary site selection and evaluation. These methods also permit the calculation of geological corrections required for geodetic gravity studies.

atmospheric sciences

ATTITUDE-SENSING SYSTEM ON GEMINI 10 AND 12

The successful flight testing aboard Gemini 10 and 12 of an ion attitude-sensing system using a novel approach has afforded a dramatic example of the direct contribution of basic research to technological advancement. The design and development of this system, for use in spacecraft, can be directly attributed to AFCRL's knowledge of instrumentation techniques and the nature of environmental phenomena gained in the course of research on the properties of charged particles of the upper atmosphere.

Two sensor systems, one to measure pitch and the other to measure yaw--were located on booms extending out about 3 feet from the spacecraft. Each sensor system consisted of 2 planar electrostatic analyzers arranged at 90 degrees to each other and having the proper voltages impressed on them for measuring the positive ions present in the earth's atmosphere.

The number of ions collected by a planar sensor depends on the angle that the collecting surface makes with the angle of arrival of the ions. The angle of arrival of the ions, in turn, is determined solely by the direction of motion of the spacecraft, since the spacecraft has a velocity about eight times the thermal velocity of the ions. Thus, by aligning one sensor system about the pitch axis of the spacecraft and another about the yaw axis, both pitch and yaw angles can be determined.

This attitude-sensing system was installed on Gemini 10 and 12 and functioned extremely well. In fact, it performed so well that, on Gemini 12, it was pressed into duty by Mission Control at Houston as an operational system during long periods of the flight. Because of faulty fuel cells aboard the vehicle, it was desirable to use the AFCRL system rather than the operational inertial system in order to conserve power. But the low-power requirement offered only one advantage. Other advantages resulted from the AFCRL system's proving to be more sensitive and more precise, with a shorter response time than the operational system, while at the same time being much smaller in size, lighter in weight, and less costly. In fact, the AFCRL system was used to aid in aligning the spacecraft in proper attitude prior to retrofire.

atmospheric sciences

LIGHTNING STRIKES TO AIRCRAFT IN THUNDERSTORMS

Lightning strikes to aircraft frequently cause minor structural damage, occasionally produce moderate damage and, in rare instances, have been implicated as probably causing the destruction of the aircraft. With the advent of thin-skinned aircraft and missiles, and solid-state electronics systems, it has become increasingly important to determine the possible effects of direct lightning strikes to a variety of systems.

Multiple aircraft and surface measurements of lightning strikes have been conducted in Florida for the past three summers by AFCRL's Meterology Laboratory under the general direction of Dr. Donald R. Fitzgerald. This program, conducted jointly by AFCRL with the Aeronautical Systems Division of AFSC, the Federal Aviation Agency, and the Sandia Corporation, has resulted in 55 measured lightning strikes to an F-100F aircraft in flight. Transient currents, rf waveforms, electrostatic fields, precipita-

tion, turbulence, photographic, and radar measurements were obtained. Results from analysis of a portion of the voluminous data indicated the following:

a. The average probability of a lightning strike to the F-100F was 0.021, based on the ratio of aircraft strikes to total strikes counted during the penetration. On two exceptional days, this probability increased to 1.0 (three strikes in three trials) and 0.5 (one strike in two trials). These storms were in the early dissipating stages of their life cycle. The observations are in agreement with a suggestion made by L. P. Harrison in 1946 that an aircraft may act to initiate streamers and a lightning discharge by suddenly augmenting the field in a localized region of the storm. This effect is believed most likely to occur shortly after the storm activity has diminished to the point where natural streamer formation is difficult. It can occur in regions of little turbulence which cause no distinctive pattern on a typical Air Traffic Control radar. In normal IFR flight operations in regions of thunderstorms merged with showers and cloud decks, the routine radar avoidance of the presently most active storm portions may easily lead to flight through a decaying storm and the possibility of an isolated lightning incident to the aircraft.

b. The maximum measured in-storm electrostatic field on the aircraft surface was 3,900 volts per centimeter. Sixty-nine percent of the strikes occurred when the field was smaller than 1,300 volts per centimeter. The maximum lightning current was 22,000 amperes, with multiple-strike activity occurring with as little as 1 millisecond intervals separating the current surges.

c. The data obtained are thought to be representative of intercloud or intracloud lightning discharges and are the first data ever acquired on some of the characteristics of this type of strike. Larger and more damaging lightning effects are believed to occur with some cloud-to-ground strikes. Several efforts are in progress to measure these with surface instrumentation.

atmospheric sciences

OZONE AND THE EARTH'S HEAT BUDGET

The heat balance of the earth's atmosphere--the amount of heat received from the sun against that which is reradiated back into space--maintains remarkable equilibrium. Were this untrue, we could expect wide and erratic swings in temperature over the earth from season to season, and from year to year.

In any set of equations dealing with the atmospheric heat budget, ozone absorption in the stratosphere is a fundamental factor. For example, at about 30 km (10 mb), ozone absorption of direct solar energy contributes more than 80 percent to the atmosphere's heat, with another 10 percent of the heating resulting from ozone absorption of reflected radiation from the earth and clouds. At about 20 km (50 mb), these figures are 70 and 15 percent, respectively.

The importance of ozone in the functioning of the earth's giant meterological machine led AFCRL several years ago to establish an 11-station ozone data-collecting network covering half the northern hemisphere. Once a week balloons carrying ozone-measuring instruments are released simultaneously from each station.

Wayne S. Hering, C. N. Touart and Thomas R. Borden, Jr., of AFCRL have recently applied the resultant wealth of ozone data to problems of the stratospheric heat balance. In the lower level of the atmosphere--the troposphere--convection from the earth's surface is the major source of atmospheric heat. But the AFCRL study is confined to the stratospheric heat balance. The result of the study is a greatly simplified model of the radiative balance in the stratosphere.

Three factors are involved in stratospheric temperature changes--solar heating, transport of heat by atmospheric circulations, and radiative (infrared) cooling.

Data on ozone concentrations gathered by the AFCRL network provide a basis for calculating total solar heating with an accuracy not previously possible. The net effect of the two other factors--transport and radiative cooling--can be evaluated simply by subtracting the calculated solar heating rate of ozone from the observed temperature change. This net effect is called the "balance requirements."

When this is done, one would expect to find an erratic relationship between the balance requirements and the observed mean monthly temperature, for two reasons: (1) the fluctuations in temperature in the stratosphere due to atmospheric transport processes; and (2) the expectation that heat is lost to space and exchanged with other levels by infrared emission and absorption in some nonlinear relationship to temperature. It was surprising to find that, for the warmer months, May through October, this is not the case. Instead, the balance requirements are a linear function of temperature.

This discovery has several interesting implications. One is that, during the warm months, the stratosphere must be in radiative equilibrium on the average. In other words, transport processes contribute negligibly to the change of monthly mean temperature. This is, of course, the classical view of the stratosphere; but in recent years it has been increasingly challenged. AFCRL has now substantiated the classical hypothesis.

Another implication is that the net infrared transfer of heat in the stratosphere can be calculated by an enormously simplified, yet effective procedure. Although approximations have been suggested by others, this study is the first to provide validating evidence. The dramatic proof of the new procedure is its ability to account for the observed mean temperature at all latitudes in the lower stratosphere in the warmer half year with a standard error of only about 2 degrees C.

astronomy and astrophysics

THERMAL IMAGING FOR SCIENTIFIC PURPOSES AND FOR MILITARY RECONNAISSANCE

The need to produce images in the infrared portion of the spectrum far beyond the photographic region is common to both science and military reconnaissance. The most important aspect of an infrared image, detector sensitivity being equal, is how well the imaging system can detect small changes in temperature from place to place in the image plane. This detection of small changes in radiance is called the incremental sensitivity of the system, and is of primary importance in both scientific and military-reconnaissance applications. At the same time, an infrared-imaging system must have the dynamic range to record the entire temperature range in its field of view. These two requirements typically conflict with one another. For example, if the sensitivity of the system is high enough to detect small changes in radiance in the target area, then it is usually not capable of recording large changes in radiance at the same time.

A new thermal-enhancement technique has been developed at AFCRL by Dr. Graham R. Hunt for basic-research purposes. This enhancement technique specifically emphasizes small differences in radiance from a target, yet displays the large radiance changes without loss of sensitivity. The use of such a system for a laboratory test sample is illustrated in Figure 1.

Dr. Hunt and Dr. John W. Salisbury, also of AFCRL, have applied this thermal-enhancement technique to scientific problems concerned with the nature of lunar and planetary-surface features. They have shown, for example, that thermal anomalies on the lunar surface, such as the crater Tycho, which are warmer than their surroundings during a lunar eclipse, are not warmer because of internal heat. Rather, the unique infrared images produced by Hunt and Salisbury (see Figure 2) have shown that these

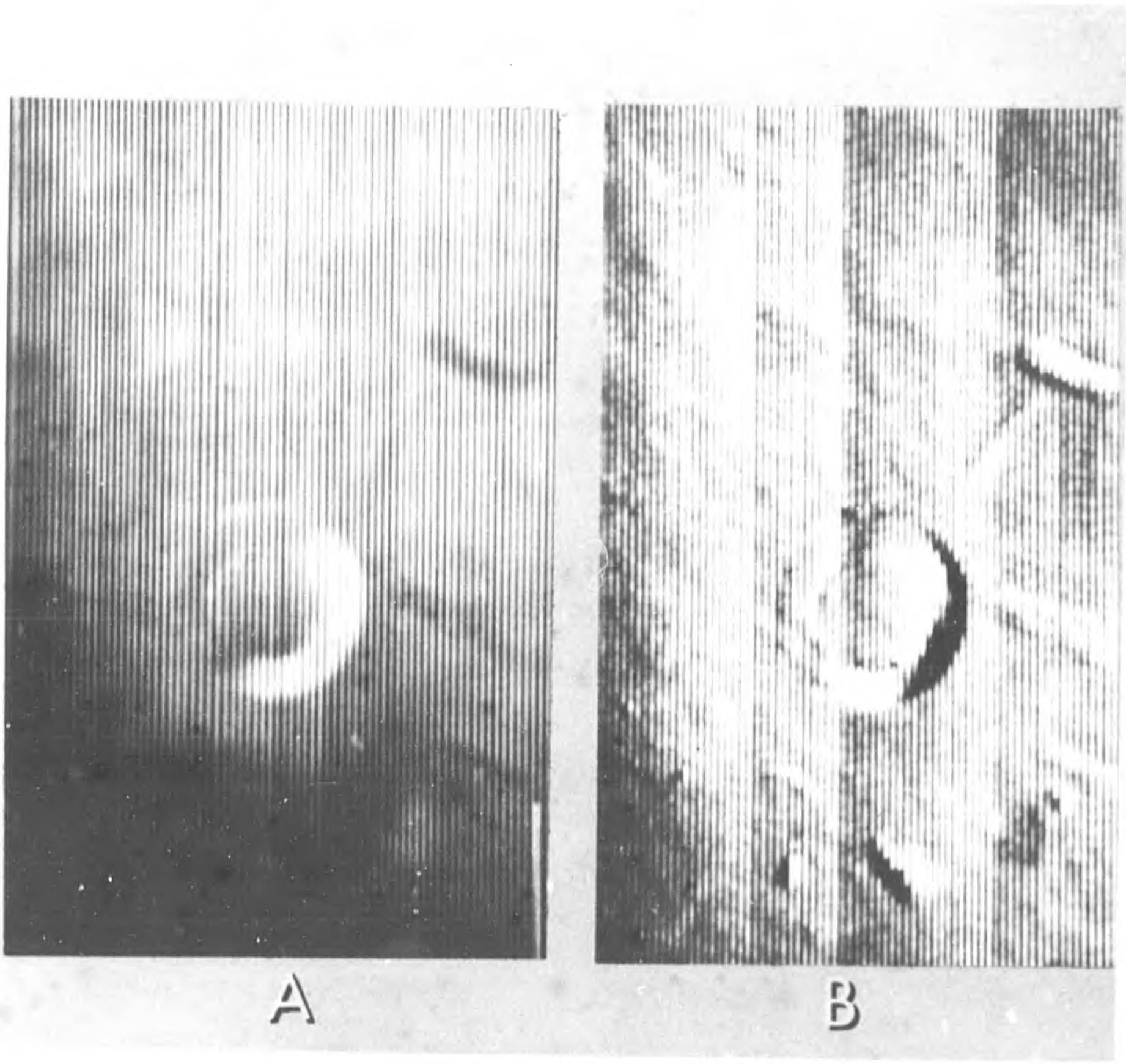

Figure 1. Infrared images of laboratory test objects (a metal washer imbedded in sand) produced (A) by conventional means, and (B) by the AFCRL thermal-enhancement technique. Note that the enhanced image more clearly displays the small thermal difference associated with the topography of the sand, while still retaining the dynamic range to show large thermal differences as well.

features are warmer because of stored solar heat.

This thermal-enhancement technique has proved to be so valuable in scientific studies that Hunt and Salisbury have joined with Lt. Winser Alexander to develop it for military reconnaissance. In co-operation with the Willow Run Laboratories of the University of Michigan, work is now in progress to construct actual flight instrumentation for improving infrared military-reconnaissance data.

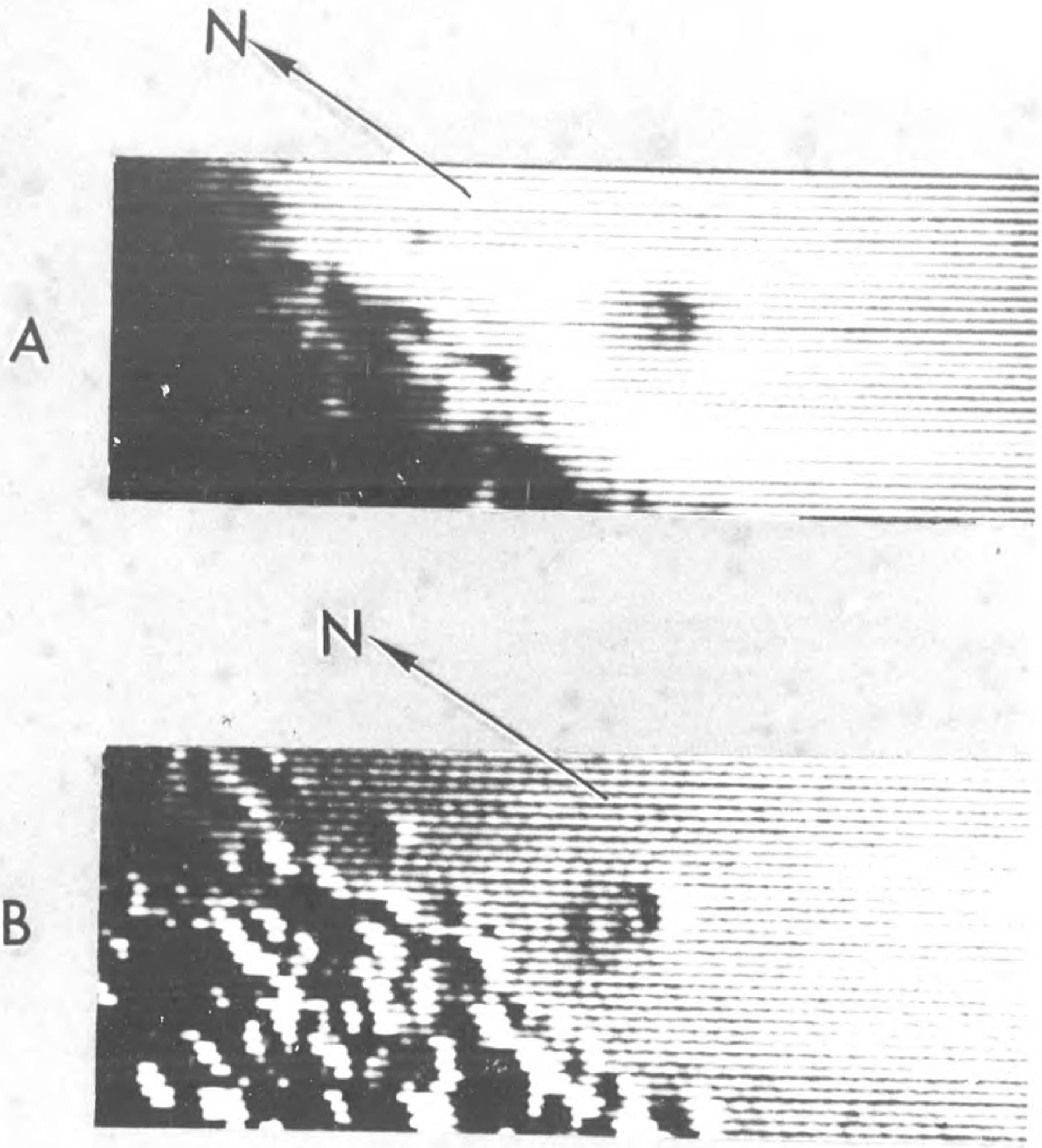

Figure 2. Infrared images of the lunar crater Tycho (center) 22 hours after it ceased to be illuminated by the sun. Darker shades of gray are warmer in these images, and the sunset line and illuminated portion of the moon is to the left of Tycho. Image A was produced by using conventional techniques, and image B by using the AFCRL thermal-enhancement technique. Note that the pattern of heat release from Tycho reflects the pattern of solar illumination just prior to sunset.

OBSERVATION AND FORECASTING OF SOLAR PROTON EVENTS

Since early 1966, continuous daily observations have been made at AFCRL's Sagamore Hill Radio Observatory at Hamilton, Massachusetts of solar flux at 5 frequencies ranging from 606 MHz to 8800 MHz. (Figure 1.) The observations have been conducted by personnel of the Air Weather Service who utilize the collected data to further their mission in space forecasting. The radio bursts emitted from solar flares are reported on a real-time basis to the Air Weather Service's SOFNET system and thence to the Environmental Science Services Administration.

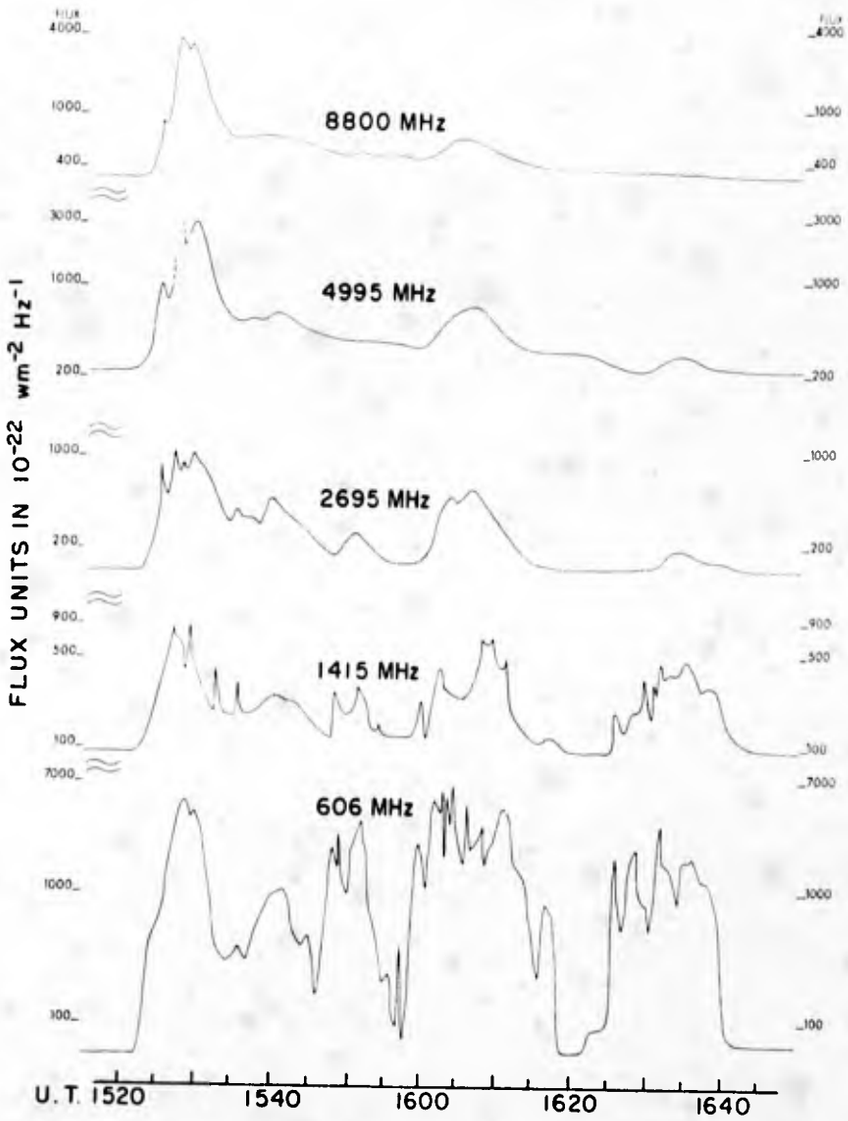

Figure 1. Complex radio burst of the solar proton event, 28 August 1966, Sagamore Hill Radio Observatory (AFCRL), Hamilton, Mass.

Protons from the sun seriously affect polar communications and a man in space. The Solar Patrol has conducted research into the sun's radiofrequency characteristics so that proton-producing flares can be distinguished from non-proton-producing flares.

In comparing the microwave characteristics of flares producing proton events with those which did not, it was found that the proton flares had high flux density in the centimeter and meter wavelengths, and lower fluxes in the decimeter region. A plot (Figure 2) of flux density as a function of wavelength of the 5 frequencies observed at Sagamore Hill exhibits a U shape. The proton flares have long durations and high flux densities. Using data gathered in 1966, and reviewing the published raw data of radio characteristics of earlier bursts, J. Castelli and J. Aarons of AFCRL and Captain G. Michael of the Air Weather Service have succeeded in characterizing proton flares. They were able to predict correctly that the large optical flare of 13 February 1967 would not produce a proton event, whereas the somewhat less intense optical flare of 23 May 1967 would. The technique was verified on the basis of these flares as well as other events. The proton flare of 23 May turned out to be the largest ever recorded in the history of solar radio astronomy.

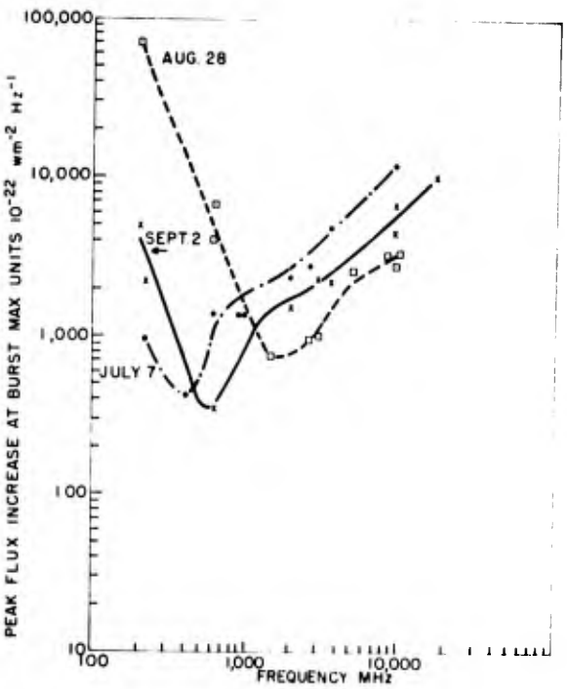

Figure 2. Radio spectra proton events, 1966. Each point for each event represents the maximum flux increase at observed frequency, generally within a few minutes of each other and associated optical flare. Observations for these events were made at Sagamore Hill; in the Netherlands; at Nagoya and Tokyo, Japan; and at the Dominion Radio Observatory, Canada.

astronomy and astrophysics

PRESTRESSED CERAMIC DRIVER CHAMBER FOR A SHOCK TUBE

Greatest shock strength from a shock tube is obtained by maximizing the sonic velocity in the driver gas. This requires the highest possible temperatures and the least molecular weight. Helium, heated to 20,000°K by an electrical discharge, is the current state-of-the-art driver. The limitation of 20,000°K was assumed to be caused by thermal loss due to radiation and/or the increase of the average molecular mass due to the evaporation of wall material.

In order to operate an electrical discharge in the driver gas, the chamber walls must be of an insulating material. At the same time, the walls must contain very high pressures (on the order of 15,000 psi). The usual container is a heavy steel chamber with a Teflon liner that insulates the steel wall from the arc. It deforms easily to transmit the pressure to the steel. Unfortunately, the Teflon evaporates rapidly above 20,000°K, increasing the average molecular weight and contaminating the apparatus.

Pure recrystallized alumina, Al_2O_3, has excellent thermal and electrical properties but, like all ceramics, has very low tensile

strength. This fault has been overcome by AFCRL by prestressing the alumina. A steel jacket 0.1% smaller than the alumina liner is expanded by heating it to 900°K and the alumina inserted. Since the coefficient of expansion for alumina is less than half that of steel, when the steel is cooled to room temperature it compresses the alumina to give an effective tensile strength sufficient to withstand an internal pressure of 45,000 psi.

The operating life of the ceramic is 4 to 100 times that of the Teflon, but both materials are about equal in price. The evaporation products from the Teflon liners contaminate the test section, as mentioned, making frequent cleaning necessary and resulting in a down time of 10-15%. When the alumina is used, down time is only about 3%. Thus, use of the alumina considerably reduces operating cost.

Two methods were used to determine the efficiency of the ceramic driver. In one, the temperature of the gas was determined from the speed of expansion into a vacuum. This assumed that no evaporation products were present. The second method was a direct measurement of the pressure of the heated gas. This would be unaffected by evaporation products. The 2 methods agree within experimental error (10%). The efficiency for conversion from electrical energy in the capacitor bank to hot driver gas is constant, to within experimental error, when plotted as a function of temperature. Since radiation and wall evaporation are strongly temperature-dependent effects, it appears that they are not significant below 28,000°K, the highest temperature attained. Efficiencies ranged from 43% for 100-psig initial pressure to 53% for 200-psig initial pressure. Shocks in excess of Mach 50 were observed. The only limitation on shock strength was the size of the capacitor bank available. The high shock strengths will permit the study of boundary-layer flow about bodies entering an atmosphere at velocities well above orbital re-entry speeds.

behavioral and social sciences

FEEDBACK EFFECTS ON TEAM PERFORMANCE

Human performance in virtually all activities is substantially influenced by information feedback. By this mechanism, people can judge their performance relative to some criterion. The effects of the level of difficulty of the performance criterion and the type, amount and timing of information feedback on performance has been extensively studied in the case of individual performance involving an individual criterion.

Recently, Professor William Howell of Ohio State University, working under Grant AF-AFOSR-985-67, has extended the study of feedback and criterion effects to situations in which an individual's performance is part of a team effort, and the criterion of performance is a team criterion. In these situations (e.g., an athletic team, military unit, office staff, etc.), information as to the adequacy of individual performance is often totally immersed in the feedback pertinent to group performance.

There are several interesting aspects to group feedback. First, it will usually underestimate the performance of the best team members, and overestimate the performance of the worst team members. Additionally, the good performance of the more capable team members will serve to make the criterion less demanding for the other members; but the poor performance of the less capable team members will make the criterion more stringent for good performers.

To better understand the impact of group feedback on the performance of individual team members, Drs. Johnston and Nawrocki of Professor Howell's staff studied the effects of group-criterion difficulty on individual performance. As a subsidiary task, they also sought to determine what effect group feedback might have on an individual's evaluation of his own performance. Simulated two-man teams performing a tracking task constituted the experimental vehicle in their

studies. Each subject was told that he had a partner and that the feedback he received would be a team score. In actuality, each subject performed alone, and the feedback he received as to whether "team" performance was average, below average, or above average, was a simple report as to whether his individual performance was equal to, above, or below a preset criterion. Three different levels of criterion difficulty were used (lenient, moderate and stringent); thus, it was as if the subject had a good partner under the lenient criterion, an average partner under the moderate criterion, and a poor partner under the stringent condition.

The results of the studies clearly demonstrate that performance in a team arrangement is affected by criterion difficulty. The individual performance of those who were poor at the task was found to vary reliably with the simulated ability level of the contrived partner. Their performance was best when the criterion was one of moderate difficulty (average partner), poorest under the stringent criterion (poor partner), and intermediate when a lenient criterion (good partner) was used. The data also demonstrate that one's evaluation of his own contribution to team performance is affected by the ability of his teammates. People tend to accept credit for good team performance, but to blame their teammates if team performance is poor.

These preliminary results suggest several potential applications of importance to anyone interested in, or responsible for, optimal performance of groups. These data imply that it should be possible to maximize the performance of a team by appropriate adjustment of its member composition. They further suggest that the notion that the higher one's goals (criteria) are the better he will perform may not be valid.

Finally, in demonstrating that the level of criterion difficulty does have an important effect on group productivity, the findings contribute to a data base from which a full appraisal and better quantification of criterion-difficulty effects may be developed. From such an expanded data base we shall more readily understand how to organize and manage group activities, such as may occur with air and space crews and work units.

environment

SIMULTANEOUS RADAR AND AIRCRAFT OBSERVATIONS OF CLEAR-AIR TURBULENCE

Simultaneous probing of the troposphere above 20,000 ft by multiwavelength, ultrasensitive radars and uninstrumented jet aircraft has given evidence that the clear-air echo regions observed by radar are turbulent on a scale that affects aircraft.

Three radars (Table I) located at the NASA facility at Wallops Island, Virginia have been used by AFCRL in co-operation with the Johns Hopkins Applied Physics Laboratory (APL) to investigate the nature of all radar echoes from a clear atmosphere. One of the objectives of this program is to determine the feasibility of using ground-based radars to detect CAT (clear-air turbulence), which has proved to be a potential hazard for aircraft operations.

The multiwavelength feature of this facility makes it possible to distinguish between

TABLE I. RADAR CHARACTERISTICS

Radar	X	S	UHF
Wavelength (cm)	3.2	10.7	71.5
Antenna dia. (m)	10.4	18.4	18.3
Beam width (deg.)	0.21	0.48	2.9
Pulse length (μ sec)	2.0	1.0	1.0
Ant. Gain (db)	58	51	35
Pk trans. power (MW)	1.0	3.0	6.0
Min. detec. sig. (dbm)	-105	-111	-111
PRF	320	960	960

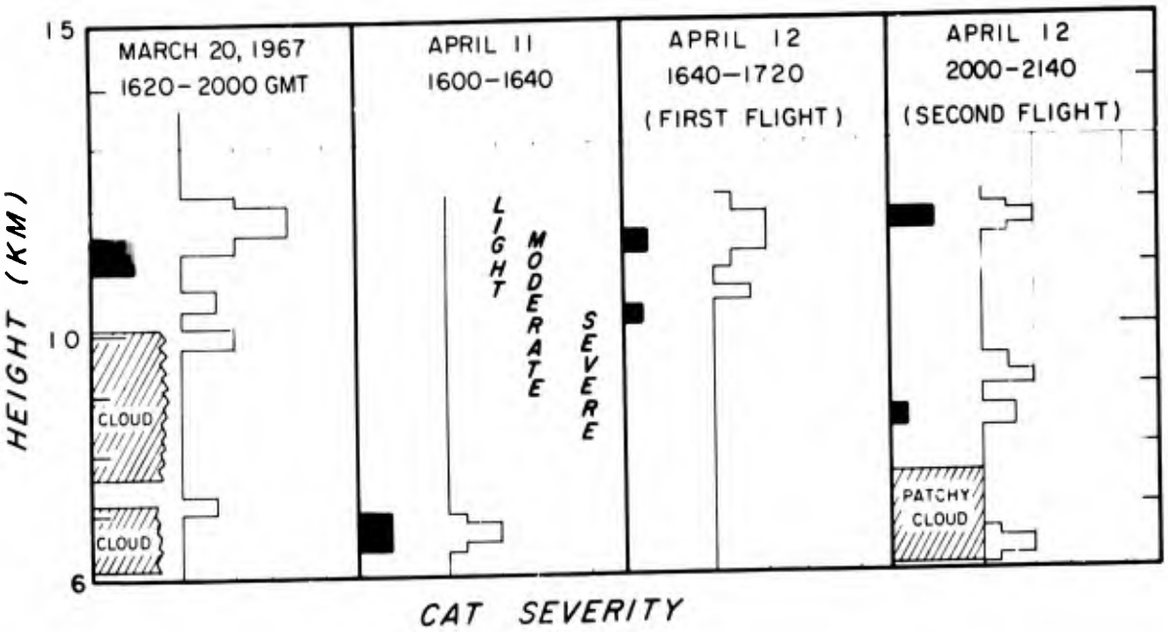

Figure 1. Heights of radar echoes and reports of clear-air turbulence. Clear-air echoes are solid, cloud echoes are hatched, and the aircraft encounters with CAT are open. The severity of CAT is indicated by a relative scale deduced from the pilot reports.

radar echoes from refractive index variations in the clear air and returns from clouds and other particles in the atmosphere. Echoes from clear-air refractive index variations have been observed in the lower troposphere and more recently in the vicinity of the tropopause.

Due to the water vapor in the lower troposphere, large gradients in the refractive index frequently exist which are detectable even when the turbulence in the region is much too small to affect aircraft. In the upper troposphere, however, the refractive index gradients are limited because of the almost negligible amounts of water vapor present at high levels in the atmosphere. Thus, there is reason to suspect that echoes from these high, clear regions are associated with some mechanical turbulence working on the weak vertical gradients to create detectable refractive index inhomogeneities. Simultaneous probing by radar and aircraft has now shown that clear-air echoes observed in the vicinity of the tropopause are indeed turbulent.

An example of the results of the experimental procedures carried out during the winter of 1966-67 will be found in Figure 1. This figure depicts the relation between the radar data and F-106 aircraft soundings. The radar procedure consisted of taking range-height photographs of the 3 radars to obtain a vertical cross section of the atmosphere along various azimuths. The aircraft performed spiral ascents and descents, level flights, and porpoise runs (a sawtooth pattern about a mean height) in regions covered by the radar scans. Pilot reports provided a qualitative estimate of the location and severity of turbulence encountered.

On all occasions, the regions of clear-air echoes above 20,000 ft which were simultaneously probed with the aircraft were found to be turbulent. This appears to be the first time that aircraft and radar have simultaneously probed the same region of space and confirmed the close relationship between the high-altitude clear-air radar echoes and turbulent aircraft flight.

The results of the winter 1966-67 observations are encouraging, but the experimental data available is still rather small. It should be remembered that these powerful radars have a limited range of 19 miles when used for

CAT detection. To study CAT detection by ground-based radars further and possibly to develop a means of determining the severity of CAT based on the character of the radar echo, AFCRL, APL, and the Air Force Flight Dynamics Laboratory will conduct a joint observational program during the winter of 1967-68. This program will combine the same type of radar observations as in the previous year with Doppler velocity studies and quantitative measurements of CAT by an aircraft instrumented for turbulence measurements.

SENSITIVE AIRBORNE GRAVITY INSTRUMENTATION UNDERGOES TESTS

The most sensitive and complete airborne gravity-measuring instrumentation ever assembled was tested recently in a month-long series of flights over the North Central United States. For these tests a KC-135 aircraft, highly instrumented by AFCRL scientists, was flown from Ellsworth AFB, South Dakota.

Although the AFCRL tests were concerned with the development and evaluation of airborne gravity instrumentation, they were part of a broad goal to establish worldwide gravity coverage. Such coverage will consist of a system of gravity profiles related to reference stations on the ground. Further in the future is a graphic representation showing lines of equal gravity intensity all over the world.

Worldwide gravity surveys have lagged because of the lack of international standards and an absolute reference system. Another reason has been the need for reliable airborne gravity survey instrumentation to make essential surveys over isolated land masses and ocean bodies.

AFCRL has steadily improved airborne gravity instrumentation since its program began in 1958. One obvious difficulty in making airborne gravity surveys is that of correcting for aircraft motion. Very slight vertical accelerations, for example, register strongly on gravity meters. An airborne computer is used to plot and make adjustments for aircraft position, speed, flight direction, and horizontal and vertical accelerations.

Aboard the test aircraft were three airborne gravimeters -- a La Coste-Rombert, an Askania-Graf, and a miniaturized quartz meter. These were mounted on precision-stabilized platforms that kept them in true vertical position regardless of aircraft attitude. These units measured changes in the vertical component of the gravity field as small as one part in one million.

The AFCRL flying laboratory has flown more than 500 hours over selected test areas in the United States and over the North Atlantic. A secondary goal of the AFCRL program is to establish the optimum altitude for making airborne gravity surveys. In this program, about 10 flights of approximately 7 hours' duration were flown at 25,000 feet. On each flight, the KC-135 flew in an east-west, north-south grid configuration of one-degree spacing.

If the earth were a perfect sphere and its mass distributed uniformly throughout, gravity values would be the same the world over. But because the earth bulges slightly at the equator, gravity is slightly lower in the lower latitudes. Superimposed on this general situation are many gravity anomalies caused by the uneven internal distribution of the earth's mass.

From the analysis of the data acquired on the AFCRL airborne gravity flights and the development and evaluation of gravity meters of increasing precision, it is hoped that techniques and standards will be set for the precise measurement of the external gravity field of the earth.

INFRARED HORIZON MEASUREMENTS

It has become apparent that stringent requirements for determining the altitude of spacecraft have surpassed the present state-of-the-art. Infrared sensors which detect and locate the Earth's horizon relative to the vehicle can be built to operate with sufficient accuracy. The limitation is that the shape or contour of the Earth's infrared horizon is not sufficiently well known. The infrared horizon is determined principally by the emission properties of the tenuous upper atmosphere, and it is not a sharp line like the earth's visible horizon.

In order to help solve this problem, AFCRL has been conducting a series of rocket flights to measure accurately the shape of e infrared horizon and to determine ! this shape varies with geographical loca ion and time of year. Although many theoretical calculations have been made, practically no useful measured values had been obtained until the flight of three rockets which AFCRL had flown recently out of a planned series of six. The first flight was partially successful while the others were completely successful. One of the major difficulties of such pro-

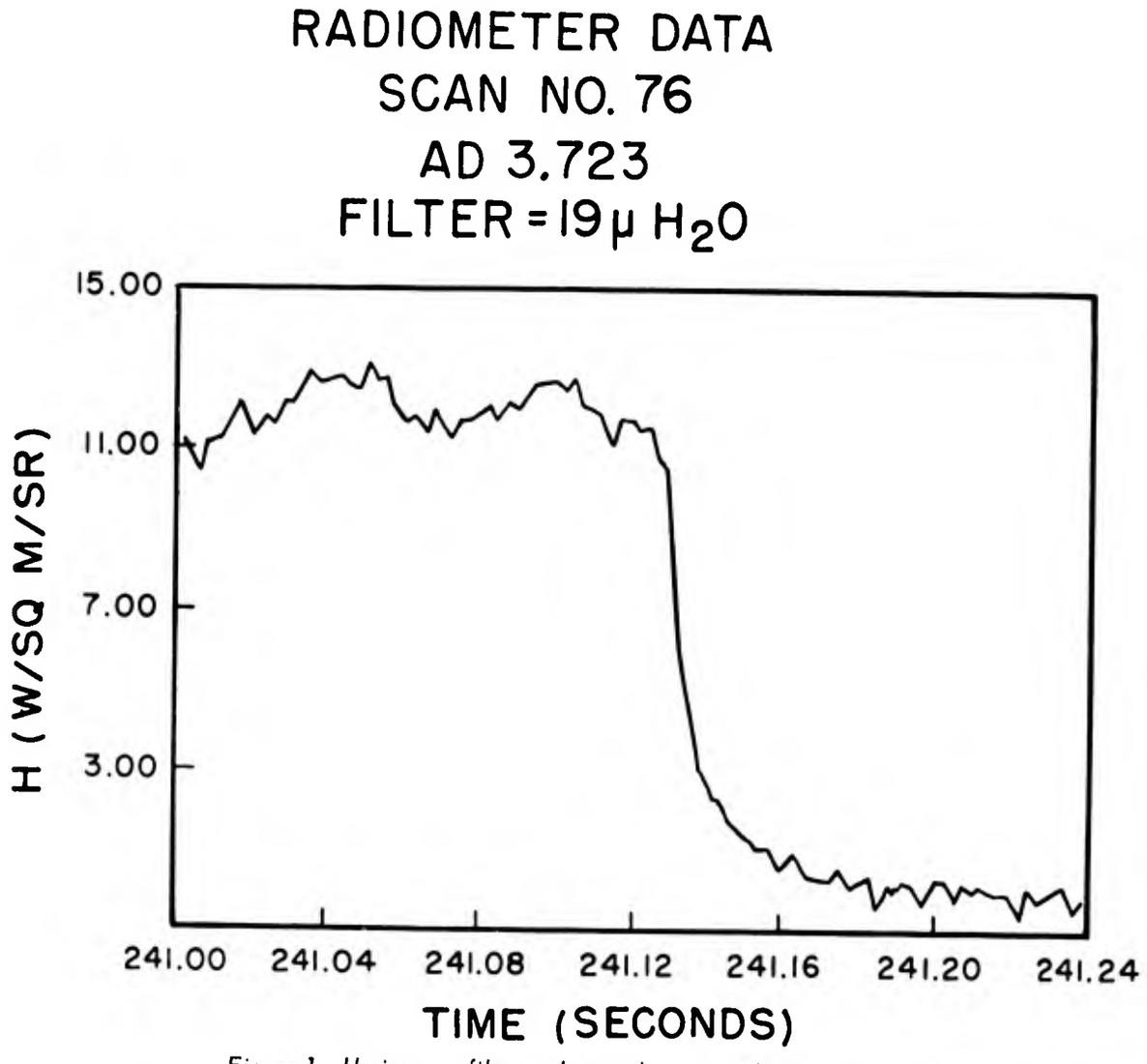

Figure 1. Horizon profile as observed at a wavelength of 19μ.

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grams is to determine accurately, independently of the IR horizon (since this is what we are measuring), where the measuring instrument is looking. This problem was solved by using relatively simple star-scanning sensors.

Individual horizon scans typical of those obtained on the three flights are shown in Figures 1, 2 and 3. Little can be said about an individual horizon curve except to note its gross features. Large fluctuations with time are observed at 10μ. This is an H_2O window, and the large-scale intensity variations are due to the presence of clouds. These variations are the major contributors to malfunctions of orbiting horizon sensors that operate in the 10μ region. Scans at 15μ, which is a CO_2 absorption region, generally lack such large-scale fluctuations.

None of the data examined shows any evidence of effects due to clouds at 15μ, whereas the effect of clouds is always observed at 10μ. This result confirms the theoretical prediction that the CO_2 band should be free of cloud effects hence horizon sensors operating in this region would prove a stable reference.

Analysis of a large number of 15μ scans indicates that both qualitative and quantitative predictions of model atmospheres for the 15μ profile are in reasonable agreement

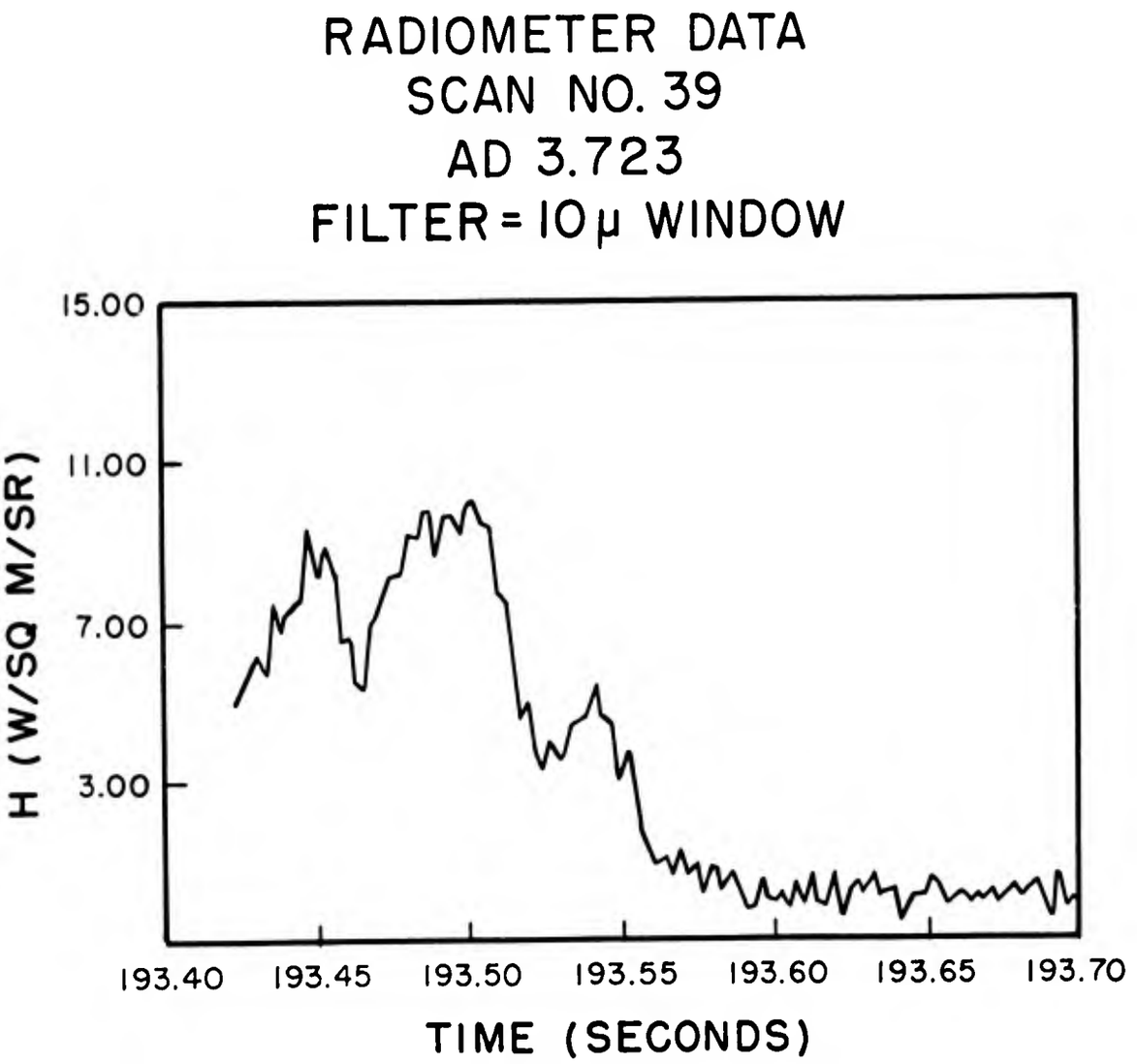

Figure 2. Horizon profile as observed in the atmospheric window region at 10μ.

with the observations. This new knowledge will permit the systems designer to proceed with greater confidence. It now appears reasonable and proper to consider a "mean profile" to represent the data and to discuss deviations from that mean.

Scans of 19μ (in the rotational H_2O band) strongly show the effects of clouds, but the effects are confined to radiance levels above 8 W m^{-2} sr^{-1}. Thus a "signal-limited" horizon sensor might achieve the high accuracy required by future systems by limiting (clipping) the response at this level. Such clipping in effect synthesizes a uniform horizon profile from the observed nonuniform one.

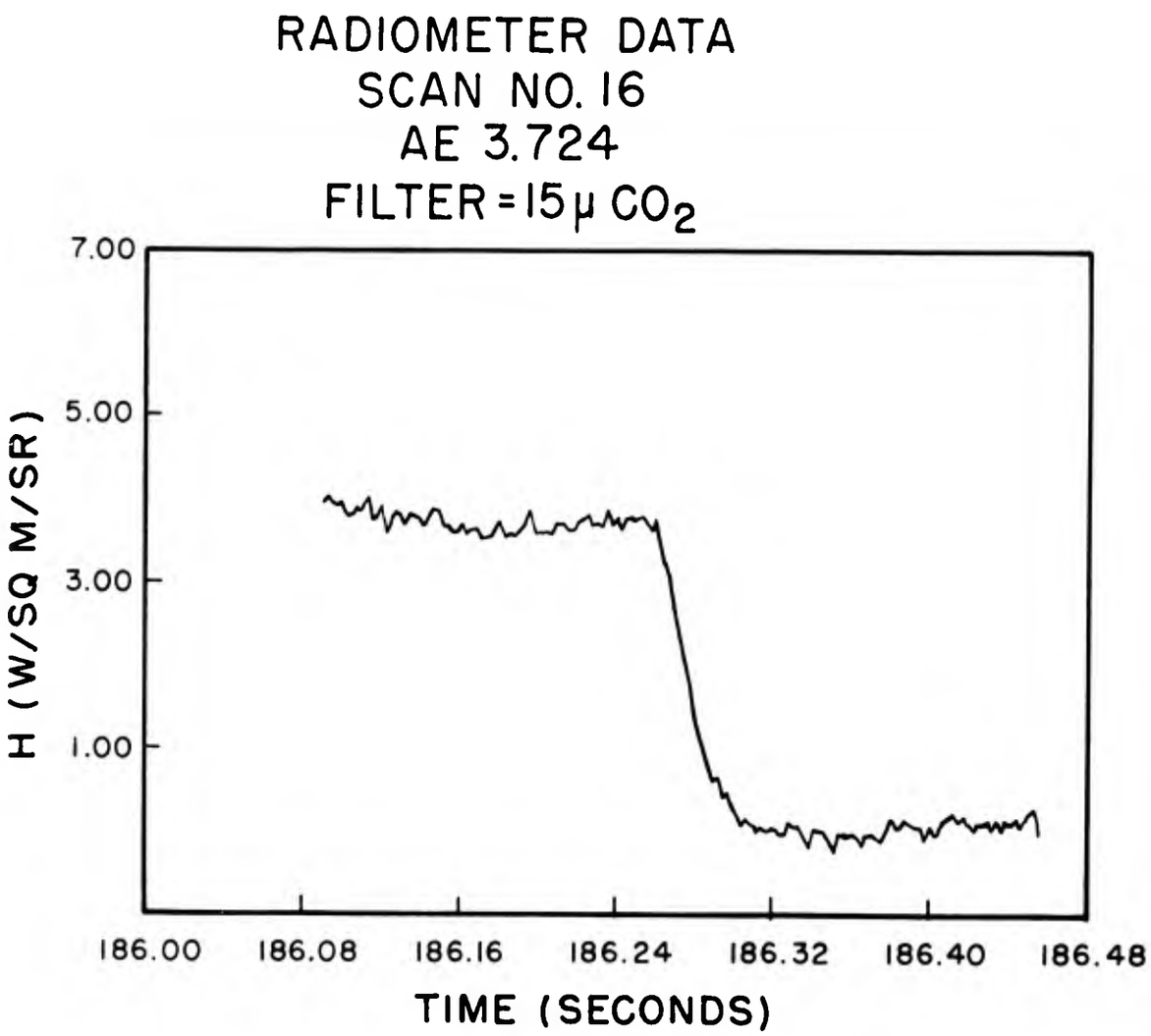

Figure 3. A typical horizon profile taken in the 15μ carbon-dioxide absorption band.

MICROSEISMIC NOISE-DETECTION SYSTEM

A highly sensitive seismic detection system for measuring small-scale earth vibrations has been developed by AFCRL scientists. The portable system was developed by Henry A. Ossing and Francis A. Crowley from commercially available components. The distinctive features of the system are its operational deployment plus a computer program for extracting maximum information from the seismic data. Using data from the multielement seismic array, the computer performs such functions as multiple-correlation, convolution, power spectral densities, and so on.

The system is designed to measure the relative intensities of environmental seismic noise at various locations. The earth's seismic noise field has many origins, with the most obvious being the slight shifts (sometimes occurring in response to lunar gravitational pull) in the earth's crustal materials. But earth vibrations are also induced by heavy surf in areas near the ocean, by trains, by rocket and missile launches and by aircraft operations.

Seismic noise affects the operations of such motion-sensitive equipments as multiple-phased antenna arrays and millimeter-wave antennas. Test and calibration of optical systems and of inertial devices for guidance control are strongly affected. Even in growing single crystals of materials, small vibrations can cause a misalignment of atoms in the crystal lattice structure.

The basic sensing elements of the AFCRL seismic array are EV-17 seismometers (built by Electro-Technical Labs) which, depending on type, detect either the horizontal or verti-

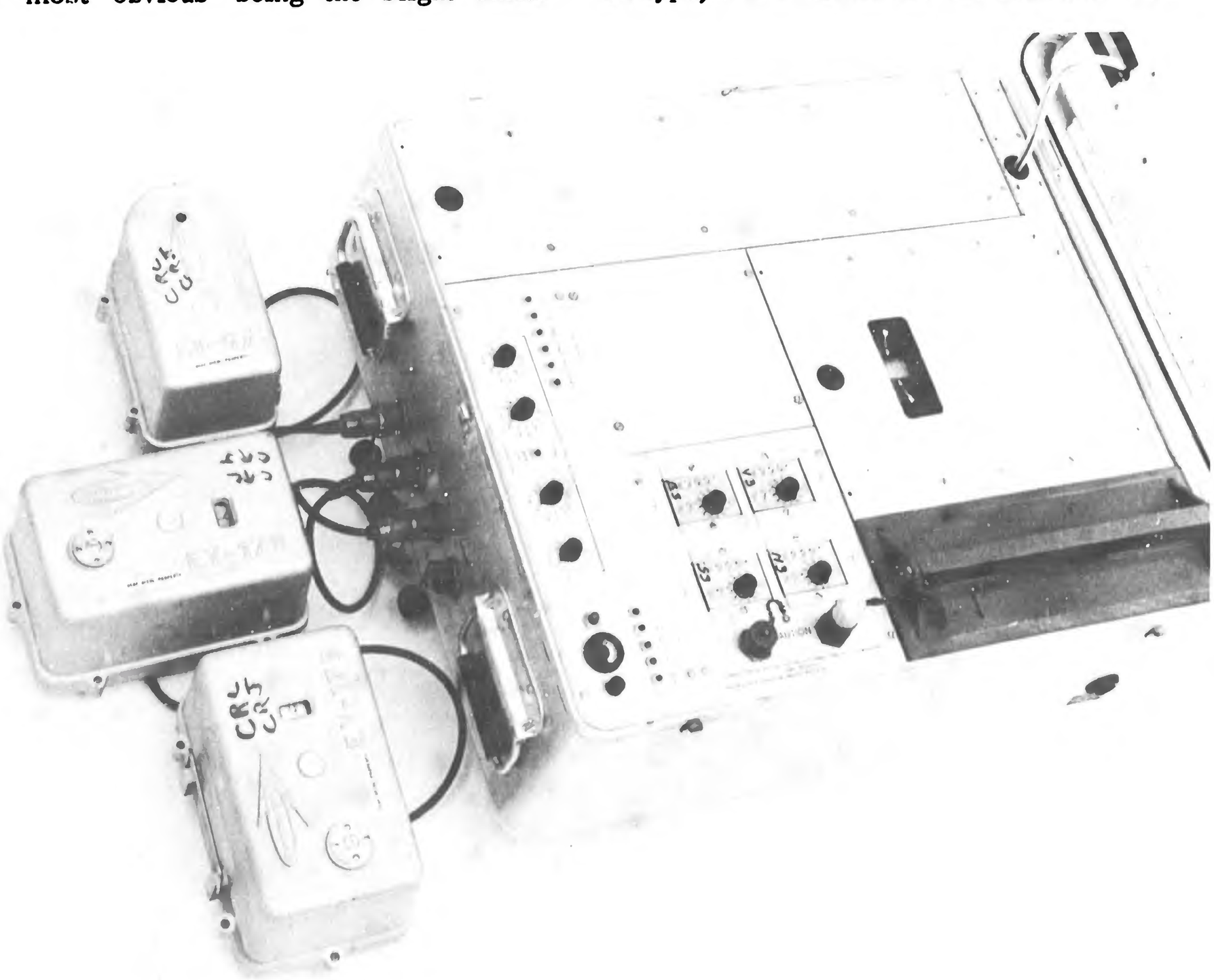

Figure 1. AFCRL's portable seismic detection apparatus for measuring small-scale earth vibrations.

cal components of vibration. These small, 13-pound, inertial-mass systems are buried 5 inches to a foot underground. Three of these seismometers (one to measure vertical and two to measure horizontal vibrations) provide inputs to a portable recording and timing package. IN AFCRL's present operations, 3 of these portable packages are used.

The three portable packages, each with its three seismometers, can be arranged in a variety of geometries, depending upon the particular investigation. To determine the direction from which seismic noise originates, the three packages are arranged in a triangle with about a half-kilometer separation. Time-of-arrival of identifiable features in the seismic noise at each station provides a basis for plotting direction. To measure attenuation of seismic noise from a known source, such as an Air Force base, the three packages are placed in a line.

Provision is made for telemetering sensor data to a central station for computer processing on a real-time basis. For most applications, however, data recorded on magnetic tape can be processed later. To improve the sensitivity of the system, provision is also made for the use of 3 additional EV-17 seismic sensors in each recorder and timing package. In this case, each package would have 6 seismometers, and the entire system would thus have 18.

The seismic noise detector has already seen several applications, most notably in a study for NASA of environmental seismic noise in the Kendall Square area of Cambridge, Mass., at the construction site of NASA's new Electronic Research Center. NASA's interest in the seismic noise level of the new laboratory arose from its planned research on inertial and optical systems.

AFCRL is presently using the system to measure the environmental seismic noise of air bases. One of the goals of the program is to possibly predict seismic noise in given locations. A magnetic-tape library of environmental seismic noise associated with air bases is now being compiled by AFCRL. The seismic system and its associated processing procedures have proved to be so effective that AFCRL scientists have found it feasible to identify various aircraft through their take-off and landing seismic signatures.

SOME RECENT RE-ENTRY COMMUNICATIONS FLIGHT-TEST RESULTS

AFCRL's re-entry communications program studies the interaction of microwave radiation with shock-ionized flow fields which form around aerospace vehicles re-entering the earth's atmosphere at hypersonic velocities. Its goal is to develop ways to alleviate or eliminate the severely degrading effects of the plasma sheath on microwave communications systems. The first in a series of six re-entry vehicles (Figure 1) instrumented to determine the influence of the plasma sheath on a microwave communication system was recently flown by AFCRL aboard a Trailblazer II rocket. This four-stage solid-propellant vehicle is able to achieve re-entry velocities of 17,000 ft per sec. Measurements included nonlinear pulse shape distortion, interantenna coupling, antenna voltage breakdown and radiation-pattern distortion. Plasma-density data were also gathered with Langmuir probes and independently with a electroacoustic probes.

Although the data have only been superficially examined so far, certain significant and heretofore-unconfirmed effects are evident. Among these is the observation of electroacoustic resonances between the vehicle skin and the plasma sheath. Radio-frequency waves are excited by the electroacoustic probes. By studying the reflections of these waves from the plasma, it is possible to determine accurately the location and density of the sheath immediately adjacent to the sensing probe. The data from the four electroacoustic probes carried aboard the vehicle will be correlated with those simultaneously obtained from three flush-mounted Langmuir probes to obtain a

profile of electron-density variation about the nose cone as a function of altitude.

Another important phenomenon observed is the decrease caused by the plasma sheath in the coupling between two antennas on the vehicle. In our experiment, a decoupling of at least 14 db was observed. Although not yet studied in detail, effects such as sheath attenuation, antenna voltage breakdown and blackout are also evident.

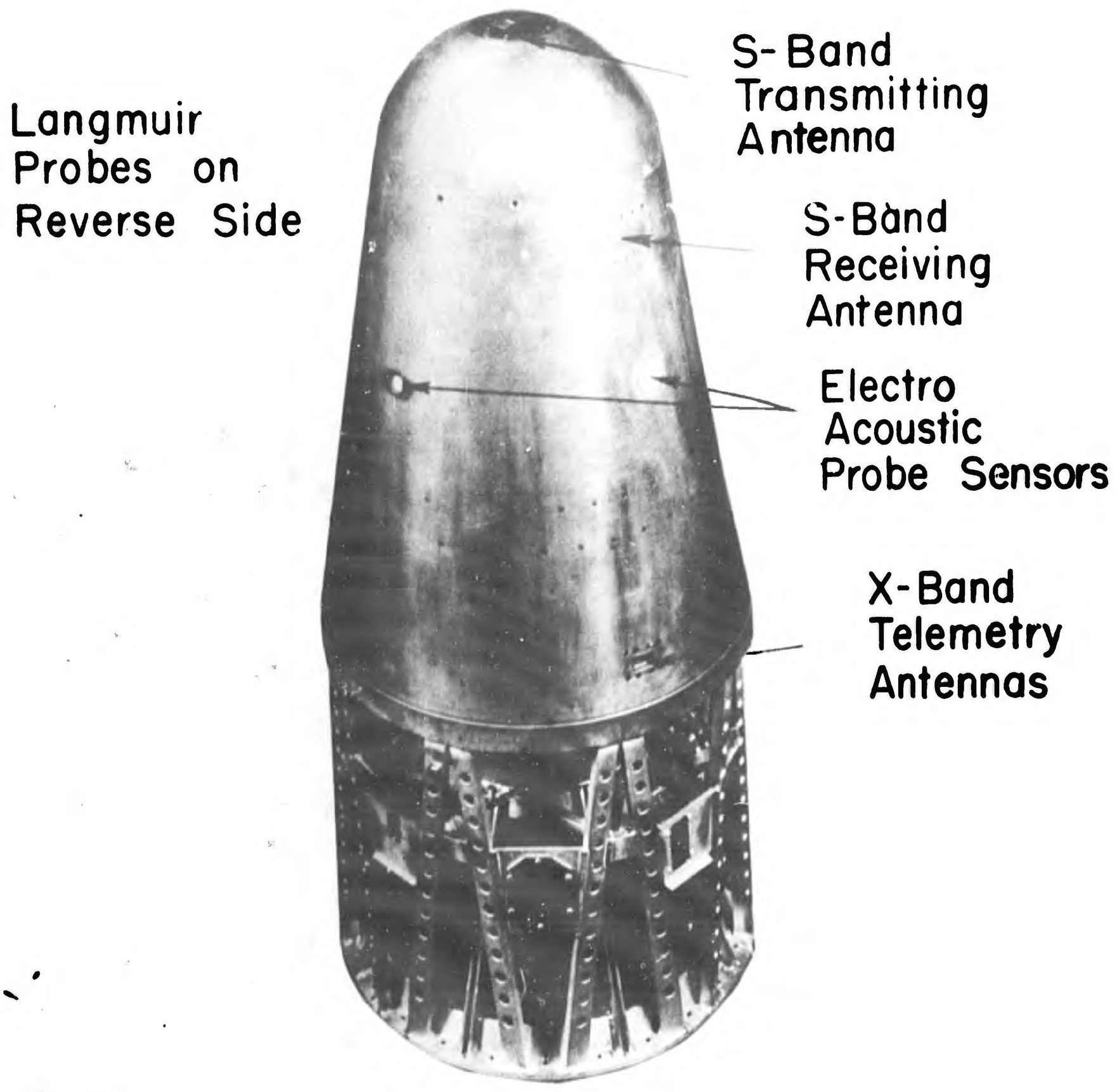

Figure 1. Trailblazer II nose cone for re-entry communications test.

RADIATION OF VOLCANIC HEAT INTO SPACE

AFCRL began a long-term study of volcanic and geothermal areas in Iceland in August 1966, as part of its program to evaluate airborne remote sensors. The program involves co-operation with the United States Geological Survey, the University of Michigan, and several Icelandic scientists. The most important result obtained so far was the detection from orbital altitude of an effusive volcanic eruption on Surtsey, an active volcanic island which has formed off the southern coast of Iceland.

Infrared emission from a fissure eruption in Surtsey, Iceland, between 19 August and 3 October 1966 was recorded concurrently by an airborne scanning radiometer and the high-resolution infrared radiometer (HRIR) system of the NIMBUS II-meteorological satellite. (See Figure 1.) Airborne infrared imagery, gathered by AFCRL's JC-130A aircraft, revealed a complex pattern of thermal anomalies outside the 1966 eruptive area. These thermal anomalies are related spatially to the 1964-65 Surtur II lava dome and associated crater features, fumaroles, flow areas and fracture patterns. Posteruptive anomalies were detected in the crater and tectonic lagoon of the pyroclastic satellite volcano, Jolnir. The anomaly on HRIR imagery appeared as a small bright spot. Radiance estimates made from geological and surface-temperature data are compar-

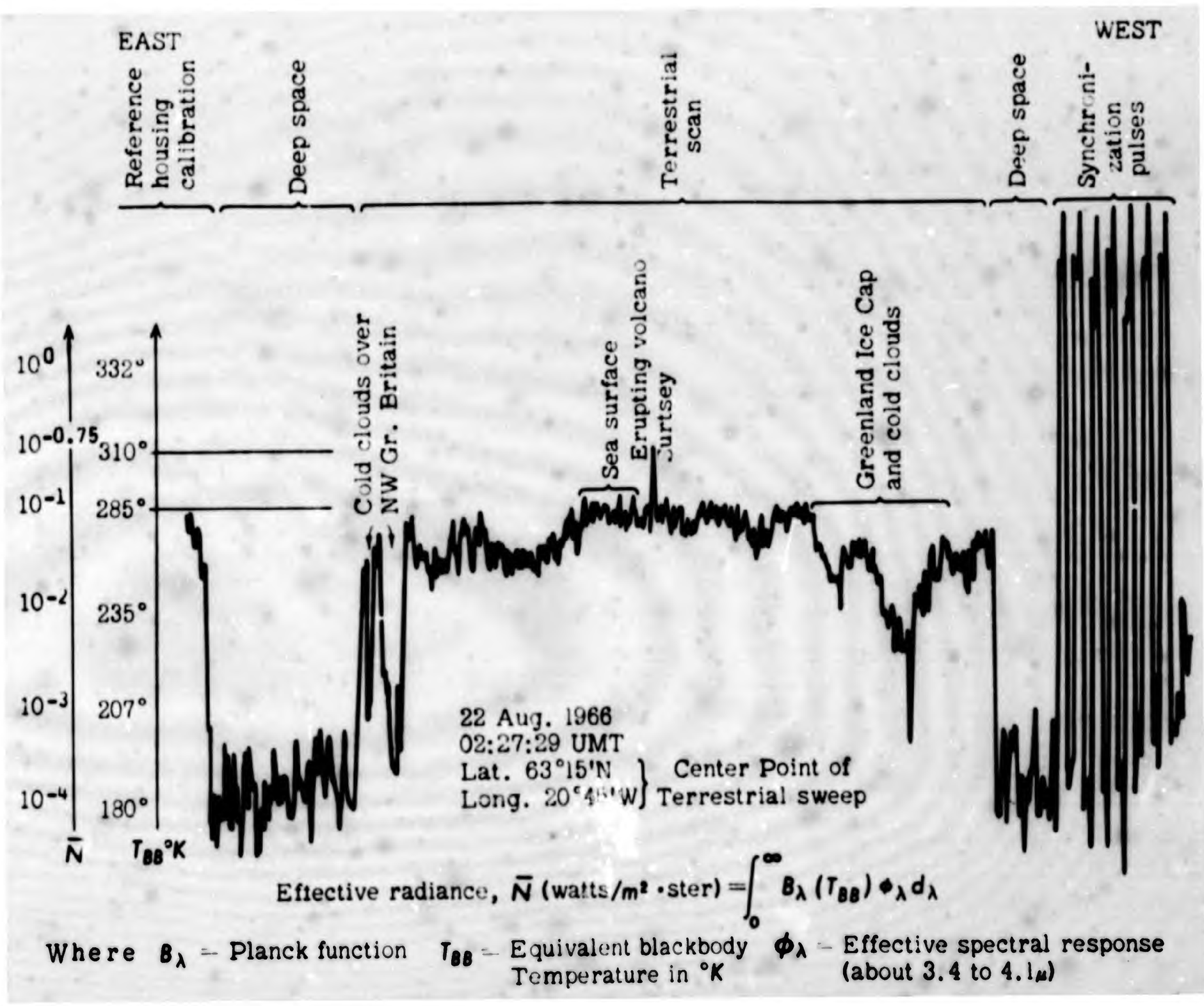

Figure 1. NIMBUS II analog record showing one HRIR scan cycle orbit 1315. (From U.S. Geological Survey graph.)

able to the 308^0 - 312^0K blackbody-equivalent temperature (radiance value of 10 - 0.75 watt/m^2·ster or 7.13 x 10^{14} ergs/sec) recorded by the NIMBUS system integrating over a 64 km^2 area that includes Surtsey.

As determined by volumetric, temperature and thermal parameter estimates, the magnitude of the volcanic event between 19 and 22 August is approximately equal to a thermal energy yield of 1.36 x 10^{22} ergs. From 1963 through 1966, the sequence of eruptions at Surtsey yielded 3.9 x 10^{25} ergs, comparable to an intensity VII volcanic eruption.

Based on these geologic and thermal data, the Surtsey thermal anomaly noted on satellite infrared imagery during August and September was recorded with an efficiency ratio of less than 0.5 percent, in part probably because of convective heat loss to the ocean and conductive heat loss to the atmosphere.

Detection of the Surtsey anomaly on Nimbus HRIR imagery demonstrates that volcanic events of this magnitude, involving major convective heat loss, can be detected and monitored from earth or planetary orbit by infrared scanning radiometry and that the efficiency ratio of detection may be characteristic of the type of volcanic event.

This research leads to the following conclusions:

1. It is possible to survey the moon and other planetary bodies for evidence of effusive volcanic activity by inserting a Nimbus-II type satellite in orbit around them;

2. Earth-orbiting satellites can successfully monitor effusive volcanic activity in remote areas;

3. Effusive volcanic eruptions may "false-alarm" a satellite that is monitoring missile launchings and chemical or nuclear explosions.

4. Successive airborne infrared surveys of volcanic areas may lead to a technique for predicting the next eruption, by monitoring changes in surface temperature.

ELECTRON-EMITTING AEROSOLS

Communications in jungle or mountainous terrain continue to be a significant problem. The ionosphere has been used for some time as a reflecting medium to extend communication ranges. This technique is limited by the continuously varying nature of the ionosphere. AFCRL is working on a technique capable of producing an artificial ionosphere which lasts for tens of minutes.

Photoelectron-emitting aerosols have been developed which can be used at reasonably low altitudes for both communications purposes and for the production of random, highly electromagnetic clouds. These materials are produced by subjecting finely ground pure sodium-chloride crystals to intense rf radiation under vacuum. The salt crystals, over a period of time, turn blue because of the formation of free sodium in the lattice. The chlorine produced at the same time is pumped off by the vacuum system. When the prepared aerosol is illuminated by light with wavelengths below 6000 A, photoelectron emission occurs.

An extensive test program on the electron emission of these aerosols has been completed by Mr S. J. Birstein and MSgt N. W. Gantick of AFCRL's Space Physics Laboratory. Using a unique current-measuring cell with a sensitivity of 10^{-15} amperes, preliminary measurements were made of electron emission in electrons per second per unit surface. These figures were then converted to electrons per second per gram of salt particles of one micron diameter. With current techniques it should be possible to produce aerosols with an electron emission of 1.4 x 10^{14} electrons gm^{-1} sec^{-1}. This would be capable of reflecting VHF/UHF signals.

ATMOSPHERIC EMISSION AND ABSORPTION AT 15 AND 35 GHz

At radiofrequencies greater than 15 GHz (20 mm wavelength) the earth's atmosphere becomes an absorbing medium due to the molecular absorption of water vapor and oxygen. Because of this strong interaction between the lower atmosphere and electromagnetic waves of millimeter wavelength, radiometric techniques may be applied to obtain information on the composition and properties of the lower atmosphere--in particular, the temperature, pressure, and relative-humidity profiles. In order to compute these profiles from radiometric measurements, it is necessary to know which theoretical formulation of absorption and emission phenomena is the best approximation to the processes occurring in the atmosphere. The parameters of interest are the atmospheric optical depth (a measure of the absorption) and the atmospheric antenna-temperature distribution (a measure of the emission).

Simultaneous radiometric measurements of atmospheric emission and absorption at 15 and 35 GHz (20 and 8.6 mm) were made for a 6-month period. Values of temperature, pressure, and relative humidity were obtained by radiosondes released during the time the radiometric measurements were being made. All data were taken on clear days at the Air Force Cambridge Research Laboratories' Prospect Hill Radio Observatory.

Optical depths were determined from the observations in three ways:

(1) using the sun as a source, the radiation received at various zenith angles was measured and the zenith optical depth was derived from these direct measurements of absorption;

(2) using the observed radioemission temperature of the atmosphere and the mean atmospheric temperature, the zenith optical depth was derived; and

(3) using the radiosonde observations of temperature, pressure, and humidity profiles, optical depths were computed from radiative transfer equation.

According to blackbody radiation theory, the zenith optical depths determined from absorption measurements and from emission measurements should agree, and they did. There was however, a difference between optical depths computed from radiosonde measurements and those obtained from radiometric measurements, indicating that values of temperature, pressure, and relative humidity derived from radiometric measurements would not represent actual atmospheric conditions.

To adjust the discrepancy, different theories of the absorption processes were reviewed. The calculation of antenna temperature using the Van Vleck-Weisskopf theory gave values consistently lower than experiment by 13% at 15 GHz and by 21% at 35 GHz. Calculations using the Boltzmann theory gave values which differed from the measured values by $\pm$ 6 or 7%. The Boltzmann theory thus explains the physical phenomena of emission and absorption of thermal radiation in the 15 to 35 GHz region to an accuracy of $\pm$.01 db. This accuracy offers promise of allowing the atmospheric temperature, pressure, and relative humidity to be recovered from radiometric emission and absorption measurements of the atmosphere.

SUNSPOTS AND SOLAR ROTATION

The sun rotates once every 27 days -- more or less. Actually, the rate varies from about 25 days at the equator to about 31 days at the poles. But the exact rotation rate is not precisely known at any given latitude because a completely satisfactory way to measure it has not been available.

A simple and widely used method of measuring the rotation rate is to observe the movement of sunspots. However a sunspot at a given solar latitude does not necessarily move with the same velocity as did an earlier sunspot at the same latitude.

Many difficulties and uncertainties arise in

using sunspots to measure rotation rates. These uncertainties have been examined by Dr. Fred Ward of AFCRL. He has re-examined almost 100 years of data on sunspot movements and reviewed the attempts of others to derive solar-rotation rates from sunspot movements.

These data show that sunspots near the solar equator move an average of 14.5 degrees of longitude each day, while those in the latitude region of 30 to 35 degrees move about 13.7 degrees each day. But it is shown that sunspot groups which have long dimensions many times their short dimensions move as much as 2 percent faster than groups of roughly circular shape, and this difference is independent of latitude. Also, small sunspot groups move faster than large groups, implying that "mature" groups slow down.

The validity of using sunspots as tracers of velocity might be questioned on several points. One is that the sunspots are continually exchanging material with their surroundings, and therefore do not necessarily move with the velocity of the ambient fluid. Since there may be variations in the velocity of this ambient fluid, sunspots may be particularly associated either with fluid in relatively rapid motion, or with fluid in relatively slow motion. Still another uncertainty in the use of sunspots as tracers of solar-rotation rates involves the determination of the center of gravity of a sunspot group. During the early stages of formation, this center of gravity shifts counter to the direction of rotation. In the decay stage, it shifts in the opposite direction. The center of gravity itself is difficult to compute because it is not always possible to observe very small sunspots within a group, or around its periphery

After his examination of these problems, Dr. Ward concluded that the uncertainty in measuring the rotation rate is an order of magnitude larger than previously assumed. This uncertainty between 0.1 and 0.2 degrees per day. Because of the systematic errors that arise from previous methods of measurements, Dr. Ward proposes that the solar-rotation rate be derived from the day-to-day motions of a random selection of spot groups. With this relatively simple approach, he finds that the solar rate is about 1 percent higher than that calculated by Newton and Nunn, whose calculations of rotation rate are presently the accepted values.

This result has an interesting reverse twist when applied to the Air Force problem of forecasting solar activity. Since the size and shape of spot groups are directly related to their activity, the speed of the spot groups must be related to the activity also. For the first time it might be possible to forecast the birth of spots, once regular measurements of the horizontal winds on the sun become available.

ATMOSPHERE IN A COMPUTER

The atoms and molecules of the upper atmosphere are characterized by a continuous chemistry of interaction and reaction sustained by solar energy. The brief interval of a solar eclipse, for example, profoundly affects the rate of association, dissociation, recombination, ionization, and deionization of atmospheric species. The pattern of reactions changes markedly with time of day, latitude and season.

Between altitudes of 60 to 120 km, the dominant elements making up the atmospheric gas are oxygen and nitrogen. These two elements are found in many combinations, such as 0^-, 0_2^+, NO_2^-, N_2O, and so on. Reaction rates among these oxygen-nitrogen species are governed by many factors--temperature, mean free paths, and concentrations of the various species.

How do reaction rates vary with altitude and with radiation intensity? In a recent report (1), Thomas J. Keneshea of AFCRL's Upper Atmosphere Physics Laboratory discusses a computer model which helps provide answers to these questions. The model deals only with 168 possible photochemical reactions that can take place among 15 oxygen-nitrogen species, plus free electrons. The model gives the researcher a powerful tool for studying reaction rates in the upper

atmosphere under a variety of controlling influences. Because of the complex nature of atmospheric gas reactions, computer modeling affords the best available method for conducting such studies.

The model involves the solution of an extensive set of simultaneous nonlinear first-order differential equations, and the method adopted has two important features. First, the integrating increment is allowed to change freely as the calculation advances so that the solution over a long period of time can be obtained. Next, a means is provided for calculating the accuracy of the solution so that the accumulation of errors can be controlled.

The present computer model represents an extension of work in progress since 1962. The most significant change in the present model is the handling of the solution for a specie after it has gone into equilibrium or into quasiequilibrium with one or more other species. Algebraic equations used previously were not adequate to handle this basic problem. Keneshea has developed a set of exponential equations to replace the previous algebraic equations.

A seemingly simple problem that has been overcome, one that the computer had trouble coping with, was the situation where one dominant ion specie was superseded by another. When this happened, the limit of allowable charge imbalance was exceeded and the program was incapable of advancing the solution.

The computer model has been used to study the behavior of the atmosphere under scores of varying conditions--diurnal variations of charged species and neutral species at a given latitude and at various altitude strata, nuclear-weapons effects in which the solution starts with high initial electron concentrations and incorporates a continuing source of electrons, the effects of sunlight reflected from clouds and oceans on D and E layer ionization, and the variability of the atmospheric composition under eclipse conditions.

The solutions reached by the computer model have been tested against observational data by rocket probles with close agreement at E-region altitudes. In the D region, comparison of the computed models with experimental profiles indicates that the chemistry of this region requires considerably more study.

SOLAR SPICULES

The solar chromosphere is a tenuous layer sandwiched between the photosphere and the corona. Figure 1 shows its structure seen at the limb in the light of the H_α line. It appears as a fur of spicules, the tiny bright hair-like spikes projecting into the corona from the ill-defined upper boundary of a continuous layer 6,000 or 7,000 km high. These spicules feed matter and energy into the corona, replenishing the steady drain of the solar wind.

The role of the spicules in the chromosphere has been the subject of a lively controversy involving two opposing hypotheses. Figure 1 is consistent with both. According to one hypothesis, the chromosphere could consist wholly of a forest of spicules, too numerous to be individually resolved at the lower levels, but with a good number of exceptionally high individuals that are seen separately higher up. The spicules should then be surrounded by coronal gas at extremely low density and high temperature (about 1,000,000 degrees K). According to the other, the spicules could be immersed in a continuous chromospheric atmosphere of relatively high density and low temperature (about 10,000 degrees K).

The spicule-forest theory neatly explains the low intensity of high-frequency radio noise from the chromosphere. In projection, the spicules fill considerably less than 10% of the area of the solar surface, and would emit corresponding less radio noise than a continuous layer. Furthermore, many observers have detected a "second limb" on H_α filtergrams, a ghostly image of a sharply defined outer boundary somewhere near the level of the solar limb seen in white light. These observers contend that the second limb is the outer boundary of the continuous solar atmosphere, visible through the interstices

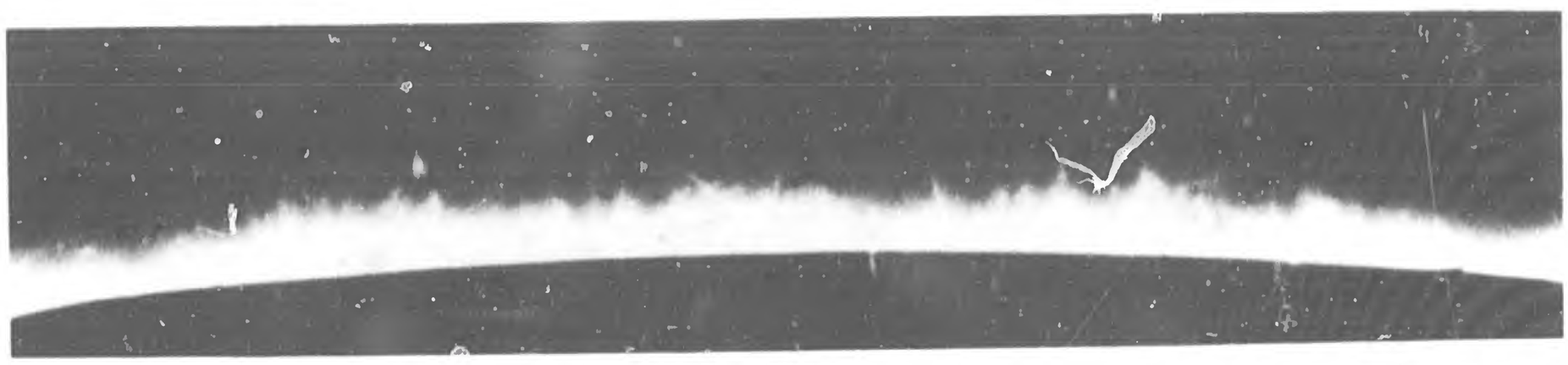

Figure 1. Structure of the solar chromosphere seen at the limb in H_α light. (Photo by Sacramento Peak Observatory, AFCRL.)

between spicules, even though the spicules are too closely packed to be seen separately. No such lower boundary should be visible in H_α if the chromosphere is continuous.

Dr. Jacques Beckers of Sacramento Peak Observatory and Dr. Robert Noyes, a Harvard astronomer visting the Observatory, succeeded in settling the question in the course of an extended study of spicule spectra.

The brightest and broadest lines in the spicule spectrum are H_α of hydrogen and H and K of ionized calcium. All of these are "self reversed" in spicules. Down the center of the bright line runs a narrow dark line or "reversal." The reversals could be produced in the spicules themselves if they are sufficiently dense. The dark lines would then share any Doppler shift of the spicule lines due to motion in the line of sight. Alternatively, the reversal could result from absorption in a cooler interspicular medium. The dark lines would then remain unshifted by the sightline motion of a spicule.

Beckers and Noyes found that the dark reversals do not share the large Doppler shifts they observed in the spicular lines. The material producing the dark reversal, therefore, is not moving with the spicule material. We conclude that the dark line is due to a stationary interspicular medium at the temperature and density favorable for the absorption of H_α, H and K. At heights above 6,000 km, the self-reversal fades out. Hence the lower spicules are immersed in a continuous chromospheric atmosphere, which interfaces rather abruptly with the hot tenuous corona at about 6,000 km. The highest spicules extend up into the corona.

Drs. O. R. White and George Simon, both of Sacramento Peak Observatory, have explained the appearance of the "second limb," which they had seen for many years and correctly interpreted. They demonstrated that every one of the instruments used to show it in H_α pictures transmitted a small amount of white light in addition to H_α. The observed second limb is simply a faint image of the usual white light limb superposed on the H_α picture. The one instrument specially designed to eliminate every trace of white light is the Sacramento Peak Observatory spectroheliograph. Significantly, it is also the only one that shows no second limb.

In the face of this direct observation of an interspicular medium, the low level of radio emission must be explained by some effect other than the inferred absence of such a medium. The medium is there.

VOICE PATTERN-MATCHING

The term "voice pattern-matching" is descriptive of a pattern-recognition process of the sort that is illustrated conceptually in Figure 1. The processing has three principal functions: analysis of the frequency and time patterns of speech; storage of a reference "library" or "vocabulary" of voice patterns in digital form; and a means of making a running comparison of the speech analyzer output with the table of stored patterns to find the stored

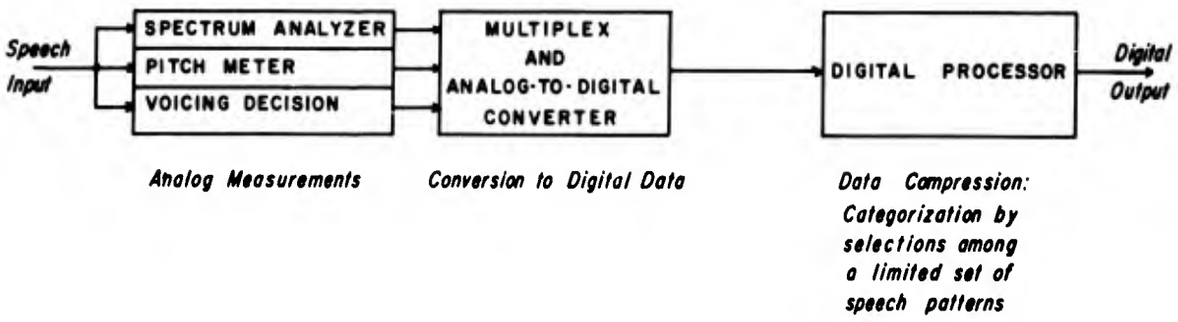

Figure 1. Digital speech compression logic.

pattern that most perfectly matches the measured speech pattern at each instant. One outcome of this process is a new categorization of the speech signal: the signal is described entirely by reference to the stored table of "standard" voice patterns. A second outcome is a constriction or compression of the speech signal representation--it becomes possible to describe the voice signal with fewer bits, to transmit speech messages with less bandwidth, and hence with greater economy and reliability. As a consequence of these considerations, this approach has particular interest for possible applications to speech communications, due to the potential for greatly increasing the number of voice channels that could be supported with existing facilities and channel allocations, for increasing the reliability of voice communications under adverse conditions, and the distance over which effective speech communications might be conducted.

During Fiscal Year 1967, Caldwell P. Smith of the Data Sciences Laboratory, AFCRL, established a new and fundamental relationship in voice pattern-matching, the significance of which may extend to pattern-recognition processes in general. The analysis of speech data revealed that the "fidelity" of a pattern-matching process, (i.e., the average error between input pattern data and output pattern representation), could be estimated by a simple equation that relates the average spectrum error to the number of patterns stored in the pattern library. This relationship leads in turn to the relationship between speech intelligibility and data-transmission-rate requirement, establishing a trade-off function from which a systems designer can estimate the data rate in bits per second that might be required in order to attain a specified level of speech intelligibility over a transmission channel.

These findings have established a firm basis for an exact characterization of processes for matching voice patterns, and have sharply focused the key questions that await further solution. Research is now centering on questions of the range and the variability of different types of voice signals, and on verifying the reliability of the performance estimates obtained with the use of the trade-off function.

POTENTIAL TECHNIQUES FOR AUTOMATIC AIRCRAFT RECOGNITION

A technique is being developed with potential applications for automatically extracting and analyzing shapes found in reconnaissance and surveillance pictures. Mr. Otis Philbrick and Capt Glen D. Wilson of the Data Sciences Laboratory, AFCRL, are conducting research with an IBM 7094 and PDP computer to test different techniques for obtaining object boundaries and syntactically describing them. Initially, the image gray tones in Figure 1 are converted to their electrical analogs. The analog is digitized and processed to remove noise and input sensor characteristics, then normalized to full scale and stored for further processing. Stored images are recalled into the

Figure 1. P-39 aircraft.

computer for "boundary detection" and "medial axis transformation."

Boundary detection is the process of determining the outline of an object in a gray scale picture. Although several detection processes are under investigation, only one is described here. This technique is a local neighborhood operation. A threshold on a difference function in the neighborhood is set to extract object outlines. The bright lines in Figure 2 result when a part of the original image is boundary-detected and displayed.

Medial axis transformation is being investigated as a means of further processing the photographs. The transformation extracts meaningful shape information from preprocessed pictures in a form suited for the automatic analysis and recognition of shapes. In Figure 2, the medial axis transformation is shown as gray lines superimposed on the white outline of the airplane. Shape information can be determined from the location of the lines and the time function of each point on the lines. This information, together with data taken directly from the contour, is structured as a syntactic description of the shape. In the future, this will provide an information base to enable computers to answer questions about objects and about relationships between objects in a picture.

Potential applications include image enhancement and automatic target recognition.

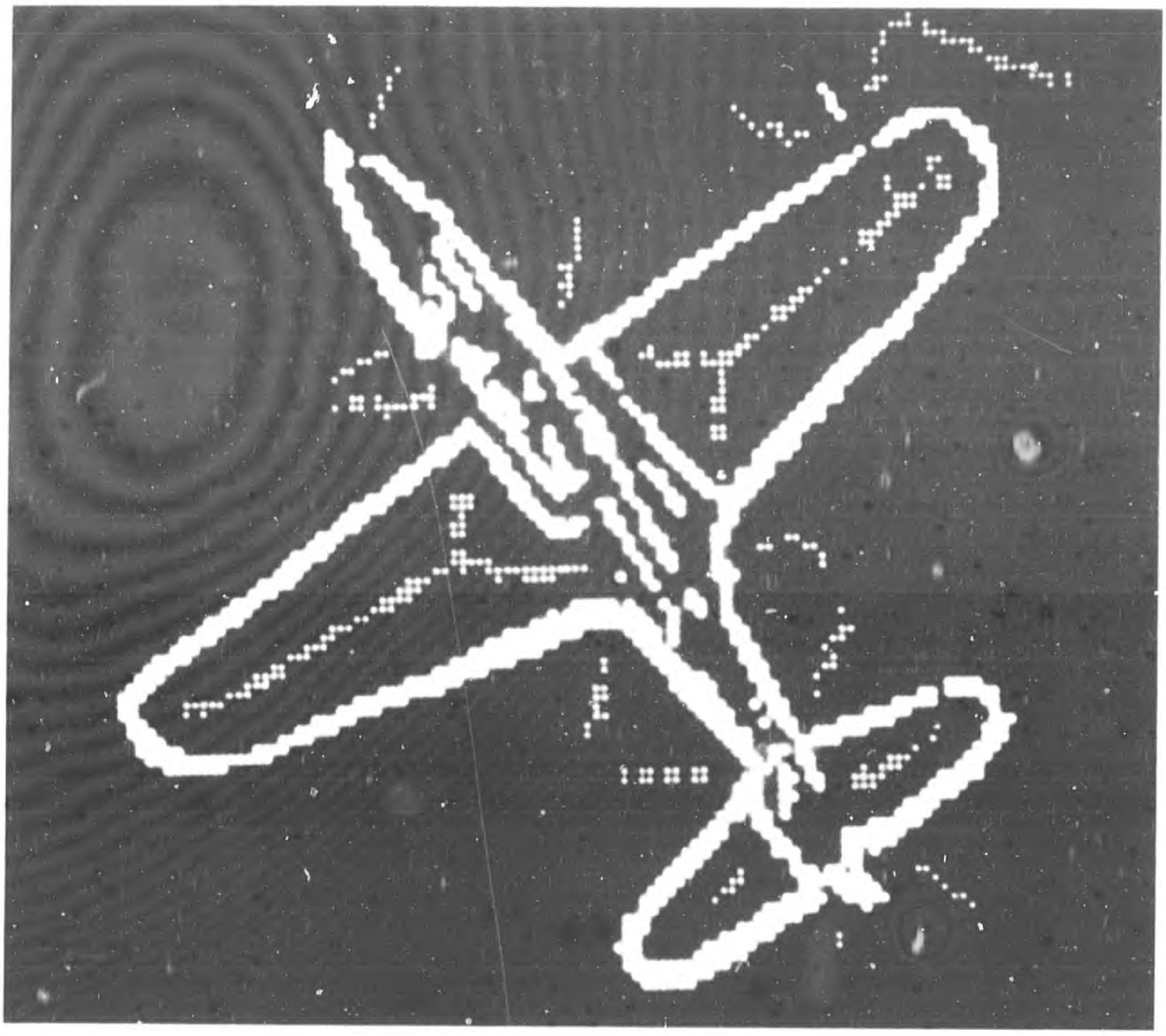

Figure 2. Boundary and medial axis transform for the P-39.

The points shown in Figure 2 could be used to enhance the original gray-tone image by emphasizing these details. Research is also proceeding in this direction. Automatic target recognition, both from reconnaissance photographs and live television scenes, could be used to find and identify targets of interest.

environmental research support

PLANETARY ENTRY SIMULATION

The NASA Planetary Entry Parachute Program was designed to evaluate at least three parachute designs suitable for soft-landing instrumented capsules on Mars. Tests of full-size models of each parachute were planned. They involved using a balloon to carry a spacecraft and balloon-control instrumentation weighing 3,000 pounds to a 130,000-foot altitude. This is equivalent to a 15,000-foot altitude in the Martian atmosphere.

AFCRL was requested by NASA to develop the balloon system, conduct the launchings, and control the balloon flights. It was noted

at the outset that a balloon fabricated from conventional balloon materials to accomplish the unprecedented payload-altitude requirement would exceed the capacity of any of the balloon-manufacturers' facilities, would be prohibitively expensive, and would create severe, if not impossible, handling and launching problems. Therefore, AFCRL developed a balloon material whose strength-to-weight ratio is approximately twice that of the conventional material. Thus, the requirement was met successfully while reducing both volume and cost by a factor of nearly 3. Even so, the resulting balloon, the world's largest with a volume of 26,000,000 cubic feet, is twice the size of any balloon previously developed or flown.

Each of the 5 balloon flights during the Program was successful. Once at altitude over the White Sands Missile Range, the spacecraft was released from the balloon. After a free fall of 180 feet, the spacecraft rocket motors were fired to accelerate the vehicle to a speed of Mach 1.6 above a 143,000-foot altitude. The test parachute was then ejected with its instrument load, to be recovered later undamaged. Preliminary results indicate that all mission objectives were accomplished. A 6th flight is planned during the spring of 1968.

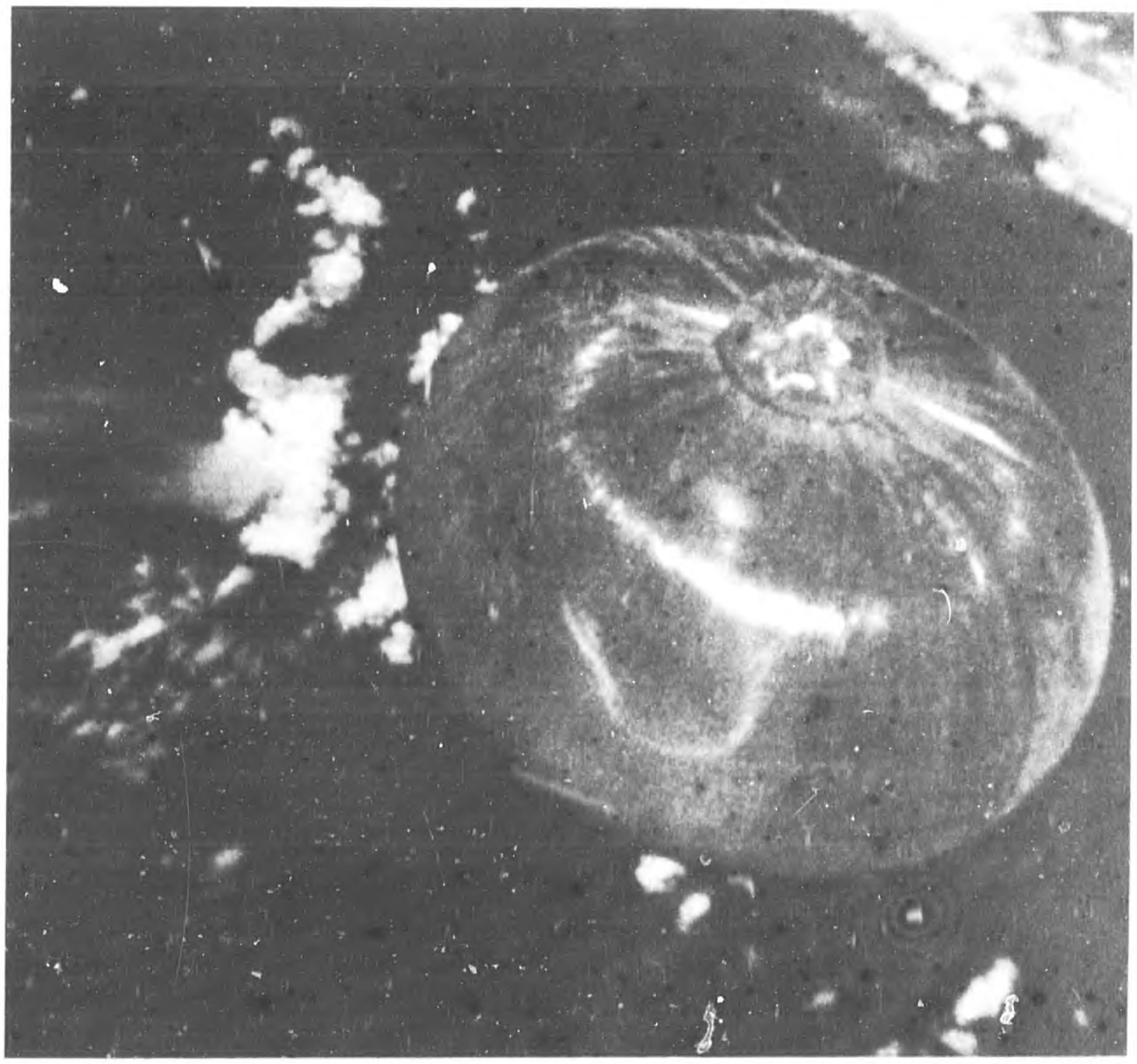

Figure 1. Twenty-six-million-cubic-foot balloon at 130,000 feet as viewed from spacecraft.

DENSITY MEASUREMENT BY INSTRUMENTED FALLING SPHERE

Knowledge of aerospace density, pressure, and temperature and their variability is particularly inadequate in the 70- to 120-km-altitude range. For several years, AFCRL has been measuring these parameters by means of experiments carried by such large rockets as the Aerobee 150, Nike-Iroquois, and Cajun.

The experiment has consisted of ejecting an uninflated sphere at an altitude of 100 km while the rocket was still on its upward trajectory. As it continued to ascend to a 160-km apogee, the sphere was inflated by isopentane vapor to obtain a large drag surface. The acceleration due to drag was then measured by a triaxial linear accelerometer as the system fell freely from approximately 120 to 70 km. The high area-to-mass ratio makes it possible to measure extremely low accelerations at high Mach numbers. Thus it is an excellent technique for measuring conditions at high altitudes.

On 9 September 1967 an accelerometer-instrumented sphere was successfully flown on a Sparrow-Arcas vehicle. This was the first known measurement of density above 100 km using a smaller, meteorological-class sounding rocket. The technique is intended to provide the Air Force with a way to obtain synoptic data needed to meet meteorological support requirements at the missile ranges. It will also be used as a relatively inexpensive means of obtaining precise data on diurnal, seasonal, and geographic variations in atmospheric density. The new system was developed by G. A. Faucher, J. F. Morrissey and R. V. Matson of AFCRL's Aerospace Instrumentation Laboratory.

Figure 1 shows the payload at the moment of separation.

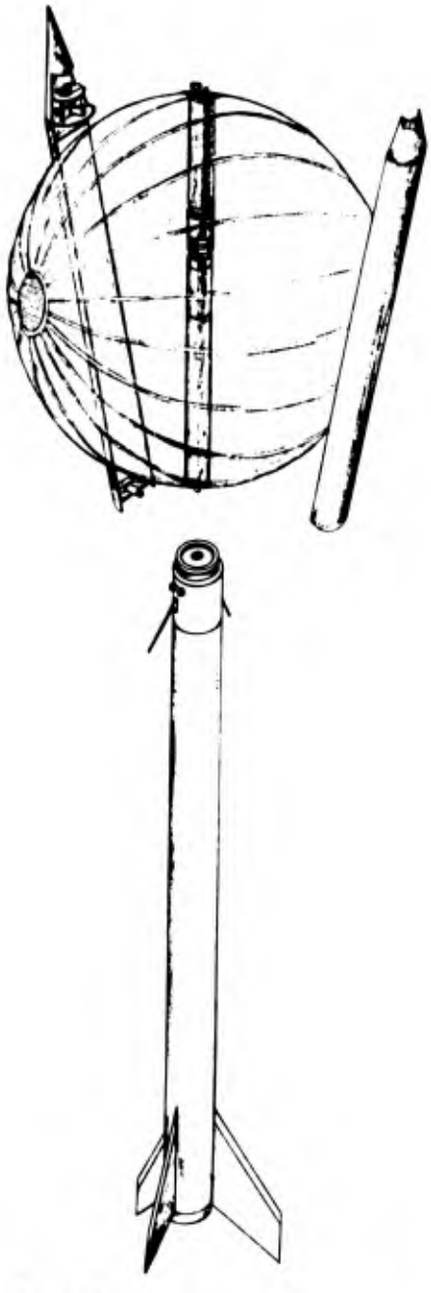

Figure 1.
Payload at moment of separation.

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This portion of the report provides information on documented material which originated in relation to the research efforts. The individuals named as contacts were chosen as a matter of convenience to facilitate the availability of information.

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Humidity Above The Hygropause

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Contact: Dr R. G. Dunn, Fluid Dynamics Facilities Research Lab, ARL. Tel. Ext. 52602.

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Contact: 1st Lt J. W. Steurer, Fluid Dynamics Facilities Research Lab, ARL. Tel. Ext. 53775.

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Contact: Lt Col G. Stalk, Directorate of Engineering Sciences, AFOSR. Tel. OX 4-5567.

Dispersion-Strengthened Metals at High Temperatures (Project No. 9782)

Contact: Lt Col G. Stalk, Directorate of Engineering Sciences, AFOSR. Tel. OX 4-5567.

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Contact: M. Rogers, Directorate of Engineering Sciences, AFOSR. Tel. OX 4-5567.

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Shaking a Rocket to Death (Project No. 9713)

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Contact: Dr D. G. Samaras, Directorate of Engineering Sciences, AFOSR. Tel. OX 4-5565.

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Biological and Medical Sciences

Disorientation in Space (Project No. 9777)

Contact: Dr R. V. Brown, Directorate of Life Sciences, AFOSR. Tel. OX 4-5041.

Fingerprinting Bacteria (Project No. 9777)

Contact: Dr R. V. Brown, Directorate of Life Sciences, AFOSR. Tel. OX 4-5041.

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PROGRAM ELEMENT 62405314

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ENVIRONMENT

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STUDIES AND ANALYSIS
PROGRAM ELEMENT 62410034

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Contact: S. J. Birstein, Space Physics Laboratory, AFCRL. Tel. Ext. 3100.

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ENVIRONMENTAL RESEARCH SUPPORT

PROGRAM ELEMENT 65402124

Planetary Entry Simulation (Project No. 6665)

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TEST INSTRUMENTATION

PROGRAM ELEMENT 65402154

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Contact: G. A. Faucher, Aerospace Instrumentation Laboratory, AFCRL. Tel. Ext. 3281.

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13. ABSTRACT

This report summarizes the progress of the Office of Aerospace Research (OAR) for Fiscal Years 1966 and 1967 in the conduct and support of research for the United States Air Force. The report covers the various aspects of management, including finances, manpower, logistics, research information activities, and planning, ~~and highlights some~~ OAR achievements in the Defense Research Sciences and Exploratory Development. A bibliography is included to aid readers in obtaining detailed information on the research programs described.

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