NASA SP-85

NASA UNIVERSITY PROGRAM REVIEW CONFERENCE

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Scientific and Technical Information Division 1 9 6 5
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

Foreword

During the past 3 years, since the decision was made to set as a national goal the landing of an American on the Moon in this decade, the university activities of the National Aeronautics and Space Administration have increased sixfold. A program of approximately $20 million in fiscal year 1962 has grown to a program of a little over $120 million in fiscal year 1965. Part of this went toward a substantial increase in NASA support of project-type research in the Nation's colleges and universities. The same period, however, saw the establishment and development of the Sustaining University Program, a coordinated effort in the support of training, research, and research facilities. This program complements the project research and provides a comprehensive university program designed to meet NASA's scientific and technological needs in a manner that not only contributes directly to NASA's mission but simultaneously strengthens the national educational complex.

NASA held its first University Program Review Conference at Kansas City on March 1–3, 1965. At this Conference, the universities reported their activities to NASA and to the other universities either working in related areas or interested in keeping abreast of the activities of the national space program.

The Conference participants were invited to discuss the nature of the work being undertaken, the manner in which it was being conducted, the results being obtained, and the impact being made. Approximately 600 representatives from colleges and universities throughout the country attended. These proceedings are a compilation of the papers presented.

T. L. K. Smull
Director, Office of Grants and Research Contracts

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Session V—Technology Utilization

Chairman: **George L. Simpson, Jr.**

Coordinator: **W. A. Greene**

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Chairman: **Donald C. Holmes**

Coordinator: **Richard M. Ulf**

The Nature and Scope of the NASA University Program

T. L. K. Smull

DIRECTOR, OFFICE OF GRANTS AND RESEARCH CONTRACTS

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, as did its predecessor agency, the National Advisory Committee for Aeronautics, recognizes the importance of a close working relationship with the educational community. Three university conferences have been held prior to this conference. The first two were aimed primarily at the rapid dissemination of scientific information that was becoming generally available through declassification as a result of cessation of hostilities—first of World War II and then the Korean Conflict. In 1962, the first University Conference under NASA sponsorship was held in Chicago. That conference was held for the purpose of presenting to the educational community NASA's views on the problems confronting it and the avenues of investigation that it hoped the university personnel would pursue in helping to further the national space program. Since that time NASA's university activities have grown at a rapid rate and at present nearly 200 universities are participating in one or more of the types of activity that comprise the NASA University Program. (See fig. 1.) This conference was organized in order to permit the universities to report on their activities not only to NASA but to the other universities that are either working in similar areas or are interested in being kept abreast of activities in the space program. A small number of participating universities will present papers on the various types of activities underway. The purpose of these presentations is to discuss the nature of the work being undertaken, the manner in which it is being conducted, the results being obtained, and, where appropriate, the impact of the program.

The way in which the NASA program was developed may provide some background and insight into the manner in which NASA approaches its relationships with universities. From its beginning in

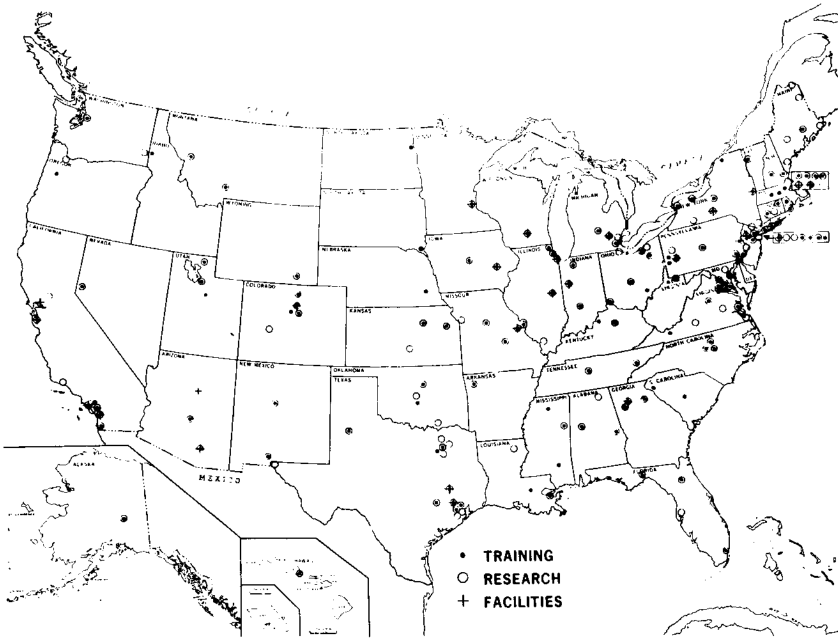

Figure 1.—Locations of participants in NASA University Program. January 1, 1965.

1958 NASA has recognized that doing business with nonprofit scientific and educational institutions is a specialized activity and has maintained within its organizational structure a group intended to serve as the focal point for NASA relationships with these organizations. This group comprises the Office of Grants and Research Contracts. It is responsible for establishing policies and procedures for NASA's dealings with these organizations and for administering those segments of the university program that emanate from NASA Headquarters. Although organizationally located within the Office of Space Science and Applications, its responsibilities are agencywide. Thus it serves all of NASA, including the Office of Advanced Research and Technology and the Office of Manned Space Flight, in administering those phases of their programmatic activities that are carried on in nonprofit scientific and educational institutions.

Figure 2 shows the most recent organization chart of NASA. In order to give a picture of NASA as it may best be viewed from the university viewpoint, figure 3 has been prepared to emphasize the role of the Office of Grants and Research Contracts and the manner in which it is situated and works within the NASA organization.

In the early days of NASA its university program consisted of what has generally been termed project research. Proposals submitted

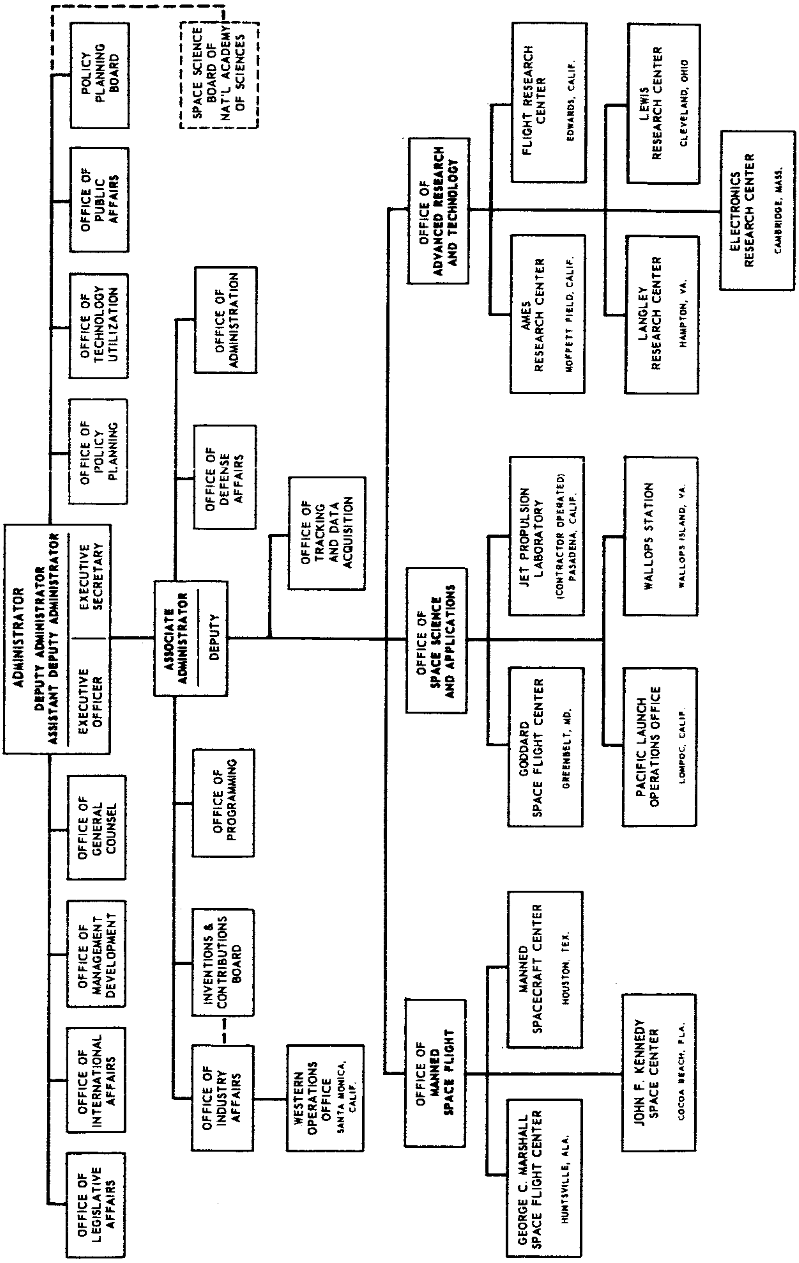

Figure 2.—Organization of the National Aeronautics and Space Administration.

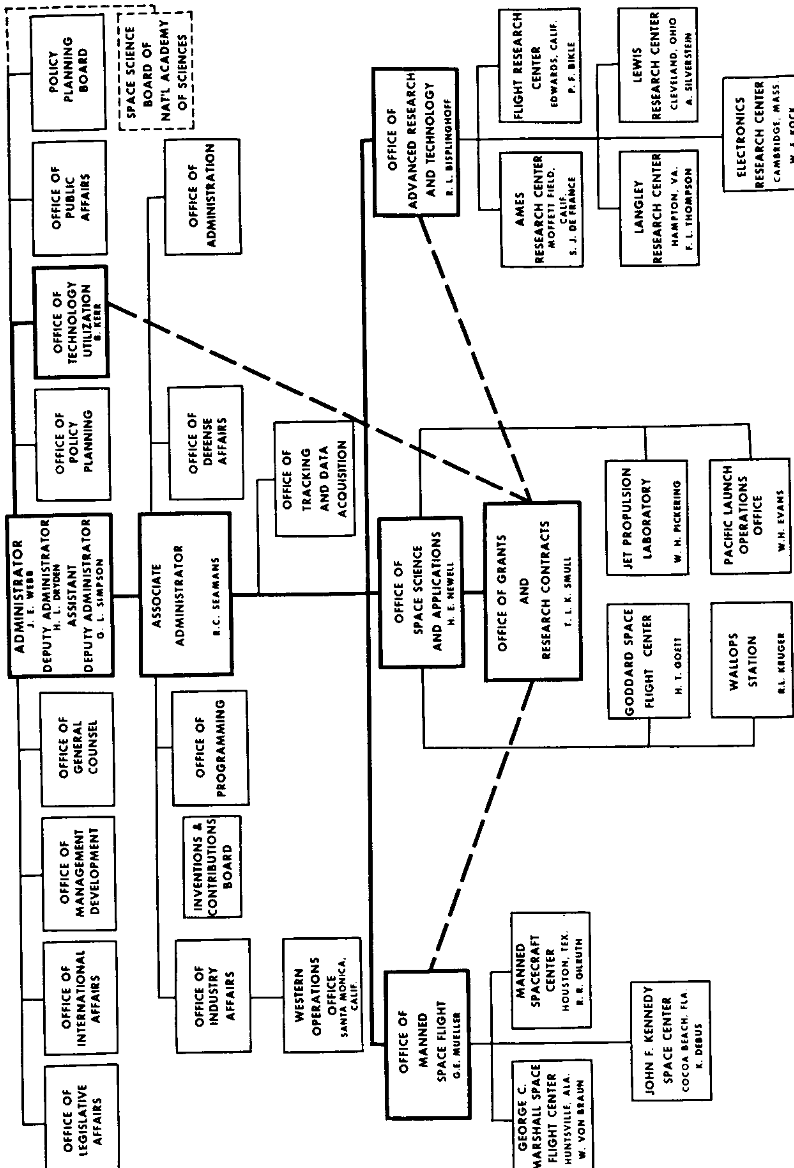

Figure 3.—University view of the National Aeronautics and Space Administration.

to NASA for studies that were considered to be of interest to the space program were evaluated and those that were considered to be either an integral part of or in direct support of rather specific requirements of on-going NASA programs were sponsored within the limits of the funding that was available. In 1961, when the landing of an American on the Moon in this decade was defined as a national goal, NASA undertook an intensive review of the scope of its university activities. It was evident from these studies that if NASA were to keep pace with the accelerated program that was set forth, it was essential that additional steps be taken to enhance the participation of the educational community in the space program. As a result, the Sustaining University Program, which will be discussed in some detail subsequently, was initiated. The growth of the university involvement in the NASA program is shown in figure 4. The funds obligated to universities have grown from a little over $3 million in fiscal year 1959 to nearly $110 million in fiscal year 1964 which has just been completed. It is anticipated that NASA's annual obligations to universities will continue to grow during the next few years but at a substantially reduced rate over that shown in this figure. For the current fiscal year, it is estimated that the total will approximate $130 million.

Further insight into the nature and scope of NASA's activities in the universities may be gained from table I which shows a categorization of NASA's fiscal year 1964 obligations to universities. In fiscal year 1964 "Research Support" amounted to just under $50 million, of which a little over $7 million was used for the specialized support of research under the Sustaining University Program. Thus a little over $42 million went for the support of project-type research.

Table I.—NASA FY 1964 Obligations to Universities

	Headquarters	*Centers*	*Total NASA*
Research support	$38 450 353	$10 776 230	$49 226 583
	*(7 156 489)	------------	*(7 156 489)
Satellite instrumentation	1 086 934	9 358 822	10 445 756
Tracking and data acquisition	------------	1 967 525	1 967 525
Research facilities	*9 142 760	------------	9 142 760
Training in space science and technology	*19 815 471	------------	*19 815 471
NASA career employee training	55 000	1 520 000	1 575 000
Apollo guidance	------------	16 286 000	16 286 000
Miscellaneous	304 382	147 176	451 558
TOTAL	68 854 900	40 055 753	108 910 653
	*(36 114 720)	------------	*(36 114 720)

*Sustaining University Program.

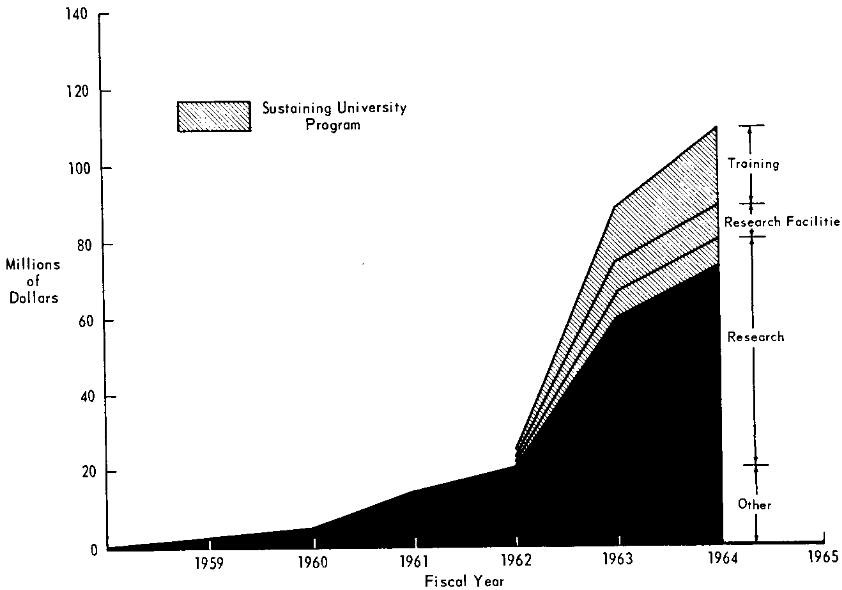

Figure 4.—NASA obligations to universities.

Although "Satellite Instrumentation" is an integral part of a scientific experiment, funds are listed separately because the rigorous environment to which they are subjected, including the necessity to withstand the forces and vibration of rocket launching and still be able to operate satisfactorily in gravity-free space makes their construction and testing an extremely complex and difficult task. The design and fabrication of suitable instrumentation is often beyond the technological capability of a university. Yet it is essential that the scientist be intimately involved in the development of his instrumentation and so this phase of the work is contracted with the university; however, in many instances it is, in turn, subcontracted by the university to specialized industries.

The next item, "Tracking and Data Acquisition," represents in large measure a service type of activity provided by a few universities in the operation of tracking stations and data acquisition and reduction in the support of range activities.

The item "Research Facilities" represents the funds made available through the Sustaining University Program for the construction of research laboratory space on university campuses.

The item "Training in Space Science and Technology" represents the activities carried on as a part of the Sustaining University Program, principally for graduate study.

The item entitled "NASA Career Employee Training" represents the university agreements entered into by NASA to provide for continued professional development of the NASA staff. This program involves, in large measure, working agreements that are established directly between the universities and the NASA Centers.

The item "Apollo Guidance" has been listed separately because of the size of the effort and because it is, to a large degree, a unique university activity. Conducted in the Instrumentation Laboratory at the MIT, it represents a follow-on by this group of an endeavor for the space program that is similar to their highly successful development of the Polaris guidance system.

The item "Miscellaneous" includes those funds that find their way into universities which could not readily be associated with the previous categories.

Although in this Conference the emphasis is primarily on programmatic activities rather than the business arrangements that are entered into to support the various programmatic studies, there are two basic features of NASA policy with respect to its dealings with educational institutions that deserve mention.

First, in the development and conduct of the NASA University program, the one basic principle underlying all NASA policy regarding its relationships with universities is that NASA wishes to work within the structure of the universities in a manner that will strengthen the universities and at the same time make it possible for NASA to accomplish its mission. While we are anxious to reap the benefits of research potential in the universities, we want to support research in the traditional atmosphere of instruction and learning from research that results from keeping the research activities surrounded by students. We are keenly aware of the need for an ever-increasing supply of highly trained personnel if we in NASA, and in fact the Nation as a whole, are to successfully carry out our goals and reap the maximum benefits of the Nation's space program. We are not interested in the creation of institutes that tend to draw university faculty away from the educational aspects of their research. The university is the only segment of the team undertaking this space program that produces manpower. The other two partners in this enterprise—industry and government—only consume manpower. It is for this reason that NASA hopes to conduct its joint activities in a manner that will preserve and strengthen the universities' educational role. This basic policy is interwoven in the policies and procedures of NASA's support of training, research, and research facilities.

The other basic policy is that of striving, wherever possible, to assure the long term funding that is so essential to the successful conduct of research. We have pioneered, within NASA, the use of a funding mechanism which has become known as either step funding or forward funding in a manner that is intended to give stability to those university programs that are known to be of several years' duration. The pattern of this type of funding is shown in figure 5. Under this arrangement funds in the amount of 100 percent of the agreed level of effort are made available during the first year. Funds in the amount of two-thirds of the agreed level of effort are programed to be paid during the second year and one-third of the agreed level of effort would be paid during the third year. When the initial grant is made, these funds are all set aside by NASA and are paid to the university on demand from the university on a quarterly basis. During the course of the investigation, based upon a semiannual review, NASA will supplement the grant annually with a grant of funds in the amount of the agreed-upon level of effort. These supplements are scheduled to be paid in accordance with the university's demand over a 3-year period, as indicated in the figure. In this manner, the university always has funds coming in for 2 additional years, at a reduced rate, should NASA decide to withdraw its support or Congress fail to appropriate funds for this purpose. This procedure permits the university to dissipate any obligations which it may have incurred in an orderly manner over a 2-year period. Although this type of funding is not appropriate for all research, it is desirable for the greater part of research activities that NASA supports because it creates stability and thereby increases research productivity. Every effort is made, when appropriate, to use this funding technique.

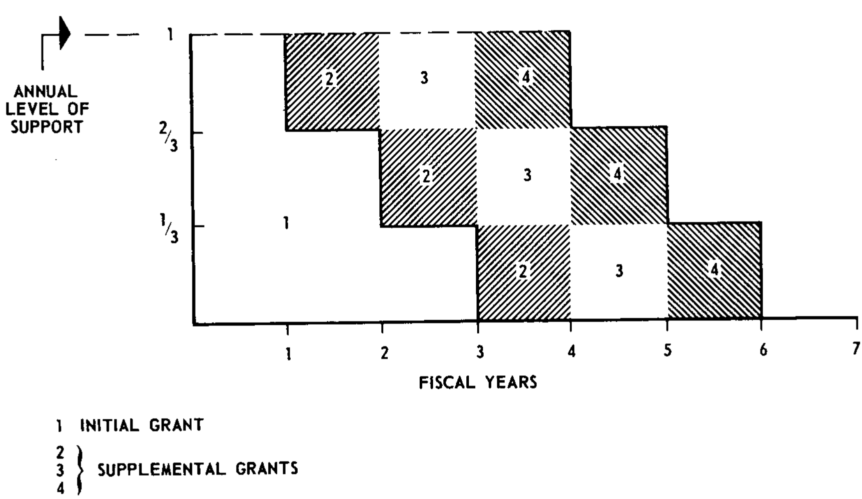

Figure 5.—Step funding of research support.

During fiscal year 1964 something in excess of $42 million was obligated to universities for the support of project-type research. This research is that which is either an integral part of or in direct support of rather specific requirements of on-going NASA programs. As a mission-oriented agency, the NASA organization has been arranged in such a manner as to support most effectively the conduct of its mission. "Mission oriented" should not be interpreted as limited to putting a man on the Moon. In fact, the first objective of NASA as stated in its enabling legislation, the National Aeronautics and Space Act of 1958 is: "The expansion of human knowledge of phenomena in the atmosphere and space . . . ." This objective certainly covers a broad spectrum of activity from research of a very basic nature to the most sophisticated type of applied research and development.

One important, interesting, and at the same time complex type of project research is that associated with the NASA space flight program. Experiments conducted in space, as noted previously, require the application of sophisticated technology and also involve long lead times that make it difficult to integrate them into a university's normal academic program. However, they represent our attack on the most fundamental and important problems confronting our understanding of the basic nature of space. The participation of the university is essential if we are to attain the greatest gains possible in this program. Several university scientists who have had experiments flown on the various tools employed for space research—airplanes, balloons, sounding rockets, satellites and deep space probes—will discuss their participation in detail in subsequent papers. There are extensive opportunities for participation in these programs (ref. 1).

NASA has three principal program offices. The mission of the Office of Space Science and Applications is largely that of determining what the space environment is comprised of and what use can be made of it. The meteorological satellites and the communication satellites are examples of applications. This office is also responsible for the unmanned space flight program as well as the scientific activities of the manned space flight program.

The Office of Advanced Research and Technology is intended to serve as the bridge that brings new ideas and concepts arising out of basic research activities to the point where they may be incorporated into operating components or systems that can be employed in either unmanned or manned space flight programs. As the title of the office implies, OART is responsible for updating technology. As such it has a broad range of interest in the whole spectrum of applied research activities, from life support systems to new and improved methods of propulsion.

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The Office of Manned Space Flight is largely operational, being charged with carrying on the manned flight programs. The outstanding success of the Mercury program is well known. NASA is now vigorously pursuing the Gemini program and the Apollo program. Because of the operational character of the manned flight program, the opportunities for direct university participation are not so extensive as they are with the Office of Space Science and Applications and the Office of Advanced Research and Technology. Nonetheless, there are important activities, the principal ones being in the medical field.

Because of its mission-oriented nature, there is a problem as to how the academic community can communicate with NASA. For example, NASA has no Chemistry Division yet it has a wide interest not only in fundamental research in many of the areas of chemistry but also in the activities of the chemical engineering departments. This lack of a one-to-one correlation between NASA's organizational structure and that prevalent in the universities is one of the reasons that NASA established the Office of Grants and Research Contracts. It is intended that through this office it will be possible for the university man to locate those counterparts of the NASA organization with which he may have a community interest. Further, this Office is responsible for coordinating these activities to insure a coherent and well integrated program. It is for these reasons that the Office of Grants and Research Contracts has been given the responsibility to receive, catalog, and insure the proper handling of all proposals submitted to NASA by nonprofit scientific and educational institutions and all unsolicited proposals from other sources.

To insure that appropriate consideration is given to a proposal, all proposals when formally submitted should be directed to the Office of Grants and Research Contracts. If discussions have been held with someone within the NASA organization, this fact shoud be in the letter of transmittal and a copy of the proposal should be sent to that person. Failure to submit proposals to the Office of Grants and Research Contracts in this manner will more often than not delay appropriate action rather than accelerate it.

Although NASA requests that all formal proposals be submitted through the Office of Grants and Research Contracts, it encourages direct communication between the university people and the scientists within the NASA organization for the exchange of information on problems of mutual interest. During the early days of NASA its organization was in a considerable state of flux and often rapid changes in personnel or, in some instances, the disappearance of organizational entities or the addition of new ones made this type of communication very difficult, if not impossible. Fortunately, this situation is considerably improved although it may be expected that any active dynamic program, such as the space program will be subject to some changes.

As a guide to those organizational entities within NASA for which there should be more than considerable interest on the part of the members of the academic community, figures 6, 7, and 8 show those parts of the organization of each of the three program offices in which the academic community should be especially interested. These groups support the project-type research activities that NASA sponsors.

In addition to the normal flow of information in the form of technical reports, Congressional reports on consideration of both NASA legislation and appropriations, technical meetings, speeches, press releases, and visits, we have recently added regular issuance of a series called Research Topics Bulletins (ref. 2) to aid the exchange of information between NASA and the scientific community. These Research Topics Bulletins, which are issued by the Office of Grants and Research Contracts (fig. 9), present discussions of areas of research in which NASA is interested or problem areas in which solutions would be helpful to the space program. The material contained in these issuances should be helpful in indicating desirable topics for thesis research as well as stimulating ideas that may culminate in sponsored research projects.

As previously noted, in 1961, when the space program was considerably stepped up as a result of the decision to place an American on the Moon in this decade, NASA took stock of its university activities with the assistance of a group of university people. Out of these studies came the ideas and recommendations that resulted in the establishment of the Sustaining University Program. It was readily evident that additional steps should be undertaken by NASA to expand and improve the partnership between NASA and the universities if the national goals in space were to be rapidly and efficiently achieved. The Sustaining University Program was established with the following goals:

An increase in the production rate of highly trained people

More adequate laboratory facilities in which to conduct research in support of the NASA mission

Removal of the interdisciplinary barrier in research and fostering of genuine cooperation between workers in collateral fields

An increased awareness by universities of their national responsibilities in the attainment of national goals

Application by universities of their unique and extensive talents to an understanding of the interrelationship of space research and technology, academic processes, industry, commerce, and society in general

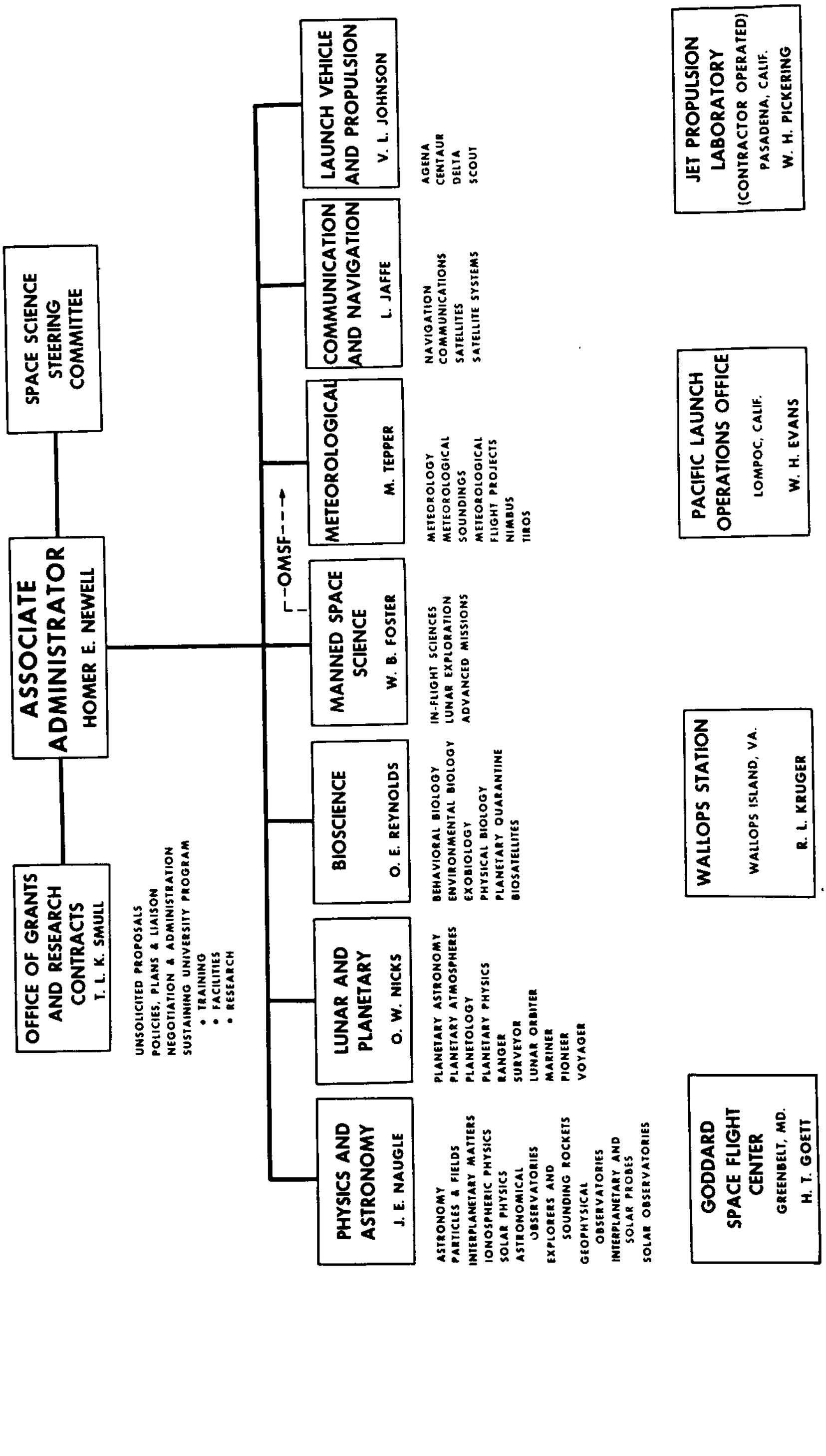


Figure 6.—Partial organization of the Office of Space Science and Applications.

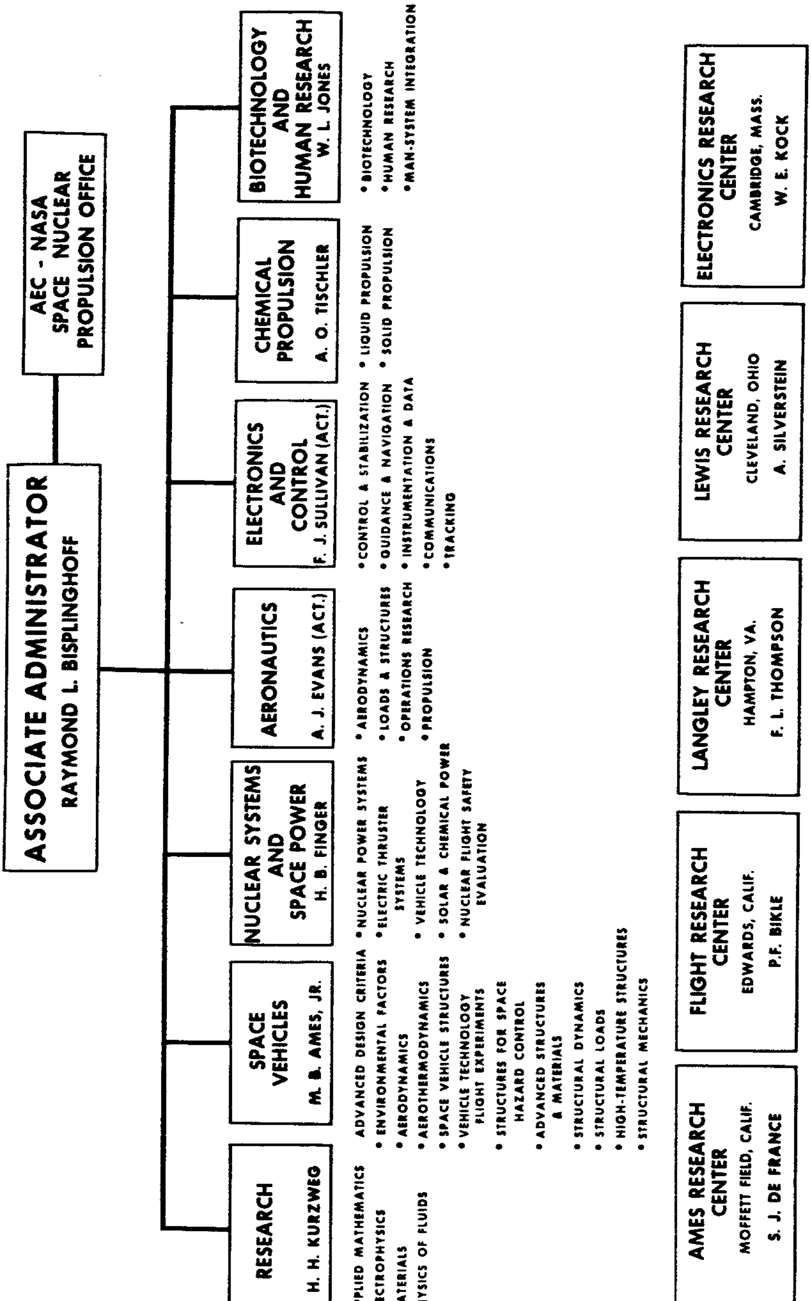


Figure 7.—Partial organization of the Office of Advanced Research and Technology.

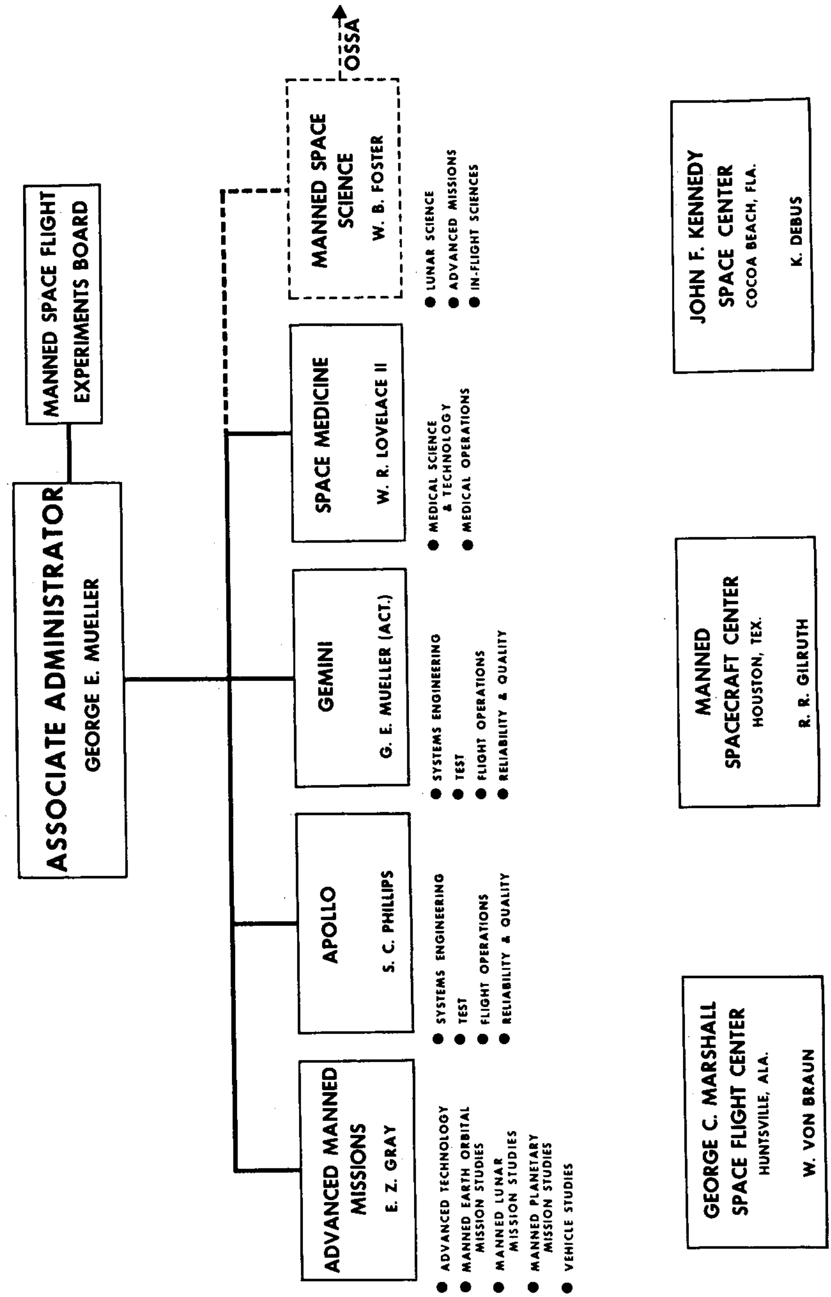


Figure 8.—Partial organization of the Office of Manned Space Flight.

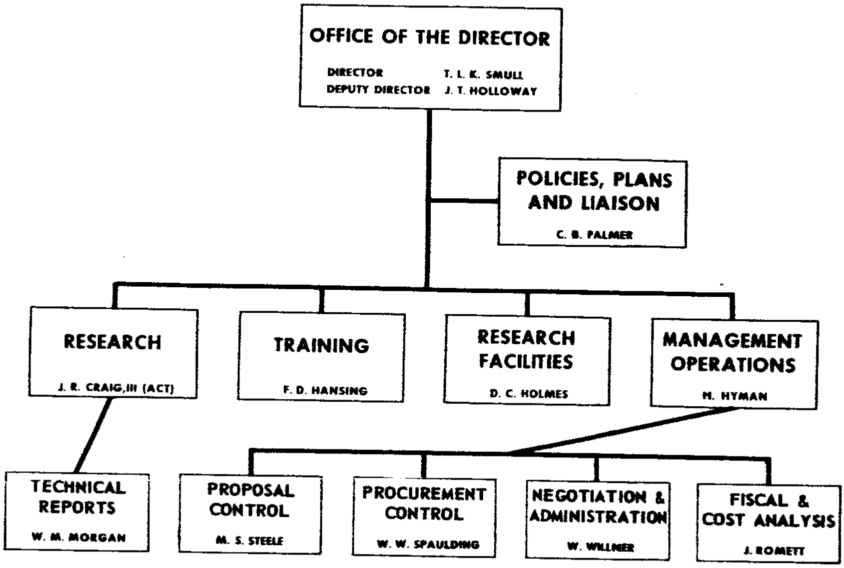


Figure 9.—Organization of the Office of Grants and Research Contracts.

At the outset, it was recognized that one of the critical aspects of the space program was the need to assure a supply of highly trained scientists and engineers required to carry out the space program effectively and efficiently. NASA felt a strong responsibility to stimulate the training of the requisite personnel and hoped to achieve this by undertaking a program of training grants. Under these grants funds were made available for stipends to predoctoral students to be chosen by the universities participating in the program; in addition, funds in the form of an institutional allowance to enhance graduate study in space science and technology at the university were included. The program thus was not only designed to accelerate the production of Ph. D.'s in science and technology but was also structured in a manner to strengthen the universities' graduate capabilities.

It was NASA's belief that by making funds available to permit a student to pursue his graduate studies on a full-time basis the time required to achieve the Ph. D. would be shortened and thus the number of Ph. D.'s produced annually would be increased. Although these graduate fellowships could be held by a student for 3 years if his progress were satisfactory, we had no preconceived notion that the doctoral degree could, or necessarily should, be attained in a 3-year period but rather that it would be appropriate for NASA to support a student for that period of his graduate studies.

NASA undertook as a goal the production of 1000 Ph. D.'s annually. It was estimated that by supporting approximately 1350 students for

3 years 1000 students might be expected to achieve their degrees. An annual starting of 1350 students would result in a steady-state program of 4000 students in training at any given time, with perhaps 1000 receiving their doctoral degrees each year.

This program was initiated in fiscal year 1962, with grants to 10 universities to cover the training of 10 students at each institution. In fiscal year 1963, 786 traineeships were established with 88 universities participating. In fiscal year 1964 there were 1071 new starts at 131 institutions. Fiscal year 1965 grants have been made to 142 institutions to support the graduate study of 1275 more students, beginning September 1965. The growth of this program is shown in figure 10.

In making these grants NASA stated that they should be made available to the best students without consideration of discipline, except that it must be one that was space related and in a field for which the university had an approved doctoral program. In other words, we made no attempt to bias the distribution of the traineeships. This natural selection procedure has produced a distribution of students by fields, as shown in table II, that we feel is very satisfactory. The aggregate 3-year distribution is shown graphically in figure 11.

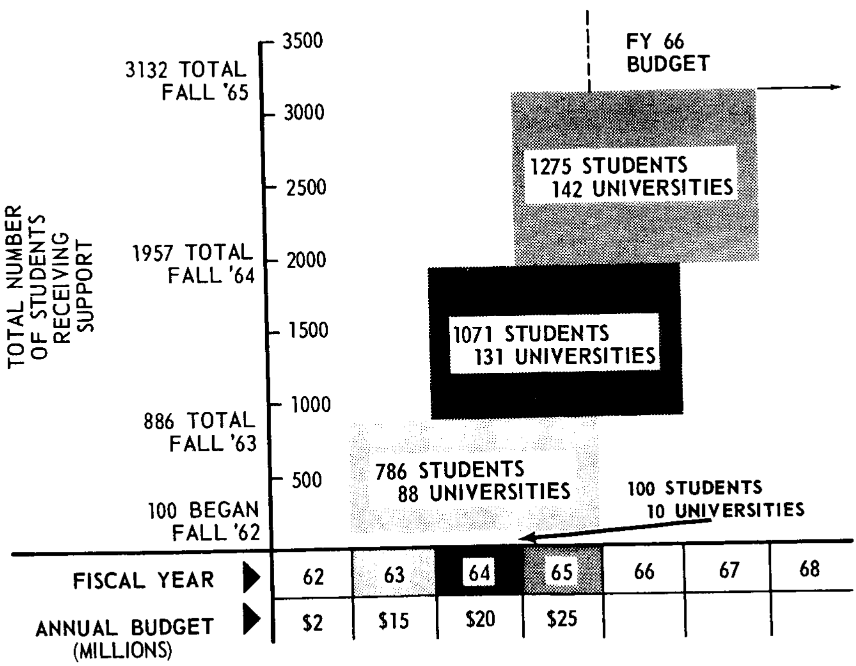


Figure 10.—History of NASA predoctoral training program.

Table II.—Distribution of the NASA Trainees (1964–65)

	1962	1963	1964
Physical sciences			
Mathematics	6	58	118
Chemistry	14	95	152
Physics	31	173	212
Astronomy	4	18	27
Geology and geophysics	2	28	35
Atmospheric sciences	1	4	12
Computer science	1	0	1
Subtotal	59	376	557
Percentage	59.0	47.8	52.0
Engineering			
Electrical and instruments	6	95	108
Mechanical	9	60	70
Chemical	5	49	59
Aeronautics/astronautics	6	43	51
Civil	0	15	18
Engineering mechanics	1	25	18
Metallurgical and materials	2	18	21
Engineering and applied science	0	9	12
Nuclear	3	8	9
Industrial	0	4	7
Subtotal	32	326	373
Percentage	32.0	41.5	34.8
Life sciences			
Zoological sciences	2	30	43
Botanical sciences	0	12	20
Biochemistry and biophysics	3	9	16
Microbiology	0	5	9
Genetics	0	5	3
Subtotal	5	61	91
Percentage	5.0	7.8	8.5
Behavioral sciences			
Psychology	3	16	29
Economics	0	3	7
Political science	0	4	7
Anthropology	0	0	1
Subtotal	3	23	44
Percentage	3.0	2.9	4.1
Other			
Business administration	0	0	4
Industrial management	0	0	1
Philosophy of science	0	0	1
Space law	1	0	0
Subtotal	1	0	6
Percentage	1.0	0	0.6
TOTAL	100	786	1071

Table II.—Distribution of NASA Trainees—Concluded

Aggregate 3-year totals	No.	%
Physical sciences	992	50. 6
Engineering	731	37. 3
Life sciences	157	8. 0
Behavioral sciences	70	3. 8
Other	7	. 3
Total	1957	100.

In 1965, there will be 3132 students studying for doctoral degrees under this program in 142 universities located throughout the 50 states. The geographic distribution of these students is shown in figure 12.

In addition to this program there are several other small training programs that comprise the training segment of the Sustaining University Program. Although comparatively small in terms of cost, we feel that they are of considerable significance. Table III shows the total activity under the training portion of the Sustaining University Program.

The Summer Faculty Fellowships are in essence a group of institutes sponsored jointly by NASA and universities in the immediate vicinity

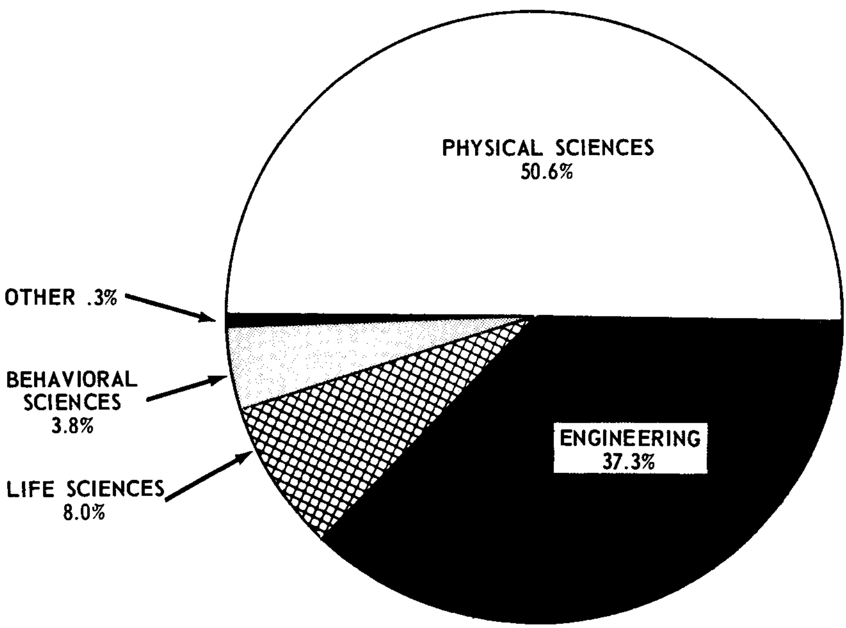


Figure 11.—Aggregate distribution of students by general field (1962, 1963, 1964).

Table III.—NASA Training Program FY 1965

Predoctoral Training

Grants made to 142 institutions to support 1275 new students for 3 years beginning September 1965.

Summer Faculty Fellowships

Joint Programs between NASA Centers and Universities. Eight- or ten-week seminars, with research in space science and engineering.

Institution	NASA Center	Participants
Auburn/Alabama U	Marshall SFC	15
Case Inst. of Tech	Lewis RC	25
Columbia University	Goddard-ISS	12
Houston/Texas A & M	MSC	15
Maryland/Catholic U	GSFC	15
Stanford University	Ames RC	27
Virginia Associated RC	Langley RC	23

Summer Institutes In Space Science and Technology

Six-week courses for nationally selected, gifted undergraduates.

Columbia University	Goddard-ISS	60
UCLA	JPL	45
University of Miami	Kennedy SC	30

Post-M.D. Training in Aerospace Medicine

Specialized medical training concerned with environmental problems of man-in-space.

Harvard University	3

Summer Program On Relativity Theory and Astrophysics

Joint Support with NSF, AEC, AFOSR, ARO, and ONR. Four-week seminar on general theory of relativity and recent experiments designed to test the theory.

American Mathematical Society	100

of seven of our Centers. They offer the opportunity for approximately 125 faculty members to get a first-hand research experience with space problems by spending some time in one of the Centers and concurrently participating in seminar-type activity conducted by the university or universities on space-related topics.

A second small program which we feel has been highly successful are the Summer Institutes which offers the opportunity for interested undergraduates chosen on a national basis to participate in an intensive exploratory program in space science or in space technology.

Two other NASA training programs currently underway are of general interest. NASA's International Fellowship Program, which involves 50 students, provides stipends for foreign nationals who are sponsored by their country for graduate and postdoctoral study in the space sciences at a number of American Universities. The other

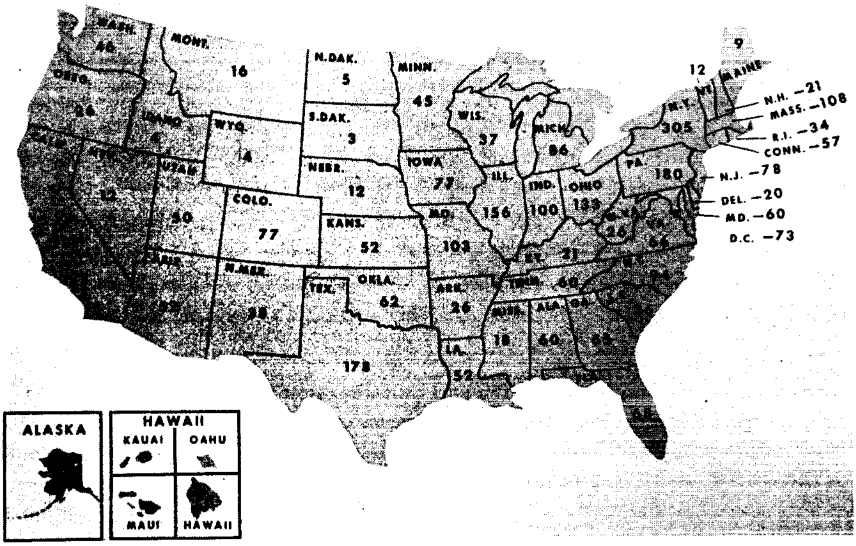


Figure 12.—NASA predoctoral students (3132) in training, school year 1965–66.

program involves postdoctoral studies at NASA Centers and is called the Resident Research Associateship Program. Seventy associateships have been established for the year 1965 for study at any of six NASA installations. Both of these programs are administered for NASA by the National Academy of Sciences.

The second segment of the Sustaining University Program is concerned with support, at qualified universities, of research that is somewhat different from that which we commonly term project research. The purposes for which these grants have been made are threefold. First, they have been used in support of broad multidisciplinary investigations.

A second important use has been for the support of research, generally in some coherent area of science or technology, to establish new groups where latent competence is apparent and there is an earnest and potentially fruitful research activity that is of interest in the space program. Grants of this nature are not large in monetary value and are aimed at overcoming one of the barriers, real or fictitious, known in the research support business as the inability to get a grant because one has never had a grant. Through this type of grant it is hoped to broaden the research base and bring selected new groups up to the level where they may compete directly for support.

The third type of use of funds made available for these special purpose grants is for grants to tie together or coordinate related projects in coherent areas of investigation. In some cases adequate support lies beyond the scope of a single project although this effort, if encouraged, would materially increase the productivity of the whole complex. Likewise, this type of research grant may serve as a base for several projects whose support fluctuates in time, to lessen the impact of such fluctuations upon the university structure.

These special purpose research grants are now in effect in some 30 universities throughout the country. Each grant has been tailored to the specific situation existing at the institution and although any one grant may be motivated by any one of the three reasons just mentioned, they all offer the opportunity for multidisciplinary studies within the institution and, accordingly, they are generally classified as multidisciplinary research grants. Figure 13 shows the location of the grants now in existence. We feel that support of research in this manner is a most effective way of permitting the universities to give full play to their competence and ability and to make their requisite contribution to the space program.

The third segment of the Sustaining University Program is concerned with research facilities grants to provide reasonably adequate working space for the universities engaged in the space program. The need for research laboratory space in universities is readily evident and it obviously will not be possible for many universities to undertake the work of which they are capable and which is necessary if national

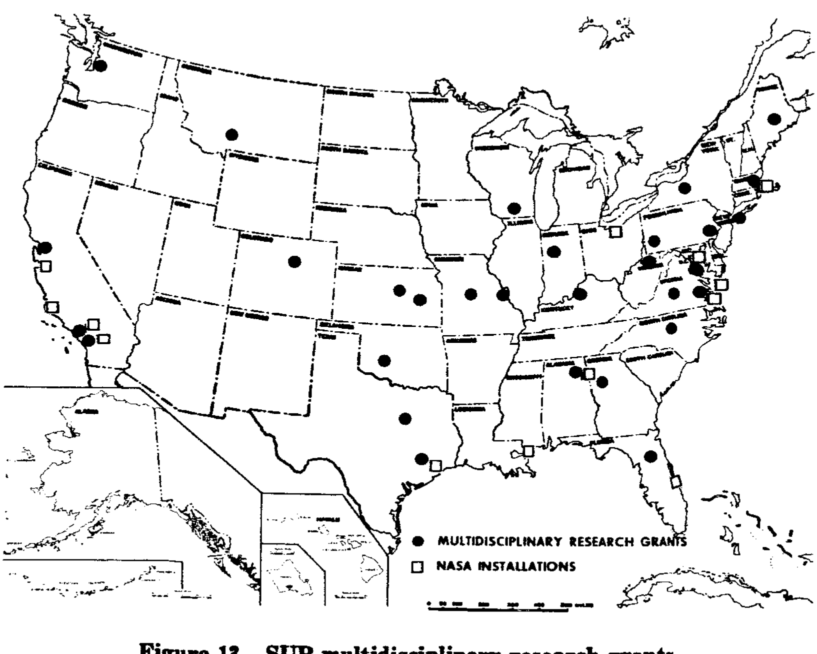


Figure 13.—SUP multidisciplinary research grants.

goals in space are to be realized unless laboratory facilities are made available. It is through the research facilities grants program that NASA hopes to carry out its responsibilities in this regard.

NASA has made 27 research facilities grants to nonprofit scientific and educational institutions for the construction of urgently needed facilities. In general, these grants have been made to educational institutions that have become active in research and have begun to make substantial contributions to the space program; by so doing they have outgrown the facilities available to them to carry on their investigations adequately. It is through this program that NASA attempts to relieve the critical shortage of facilities for groups now doing important research pertinent to the NASA mission.

The grants that have been made as of March 1, 1965, from the inception of this program in fiscal year 1962, are shown in table IV. These grants have been for dollar amounts, determined by NASA to be appropriate in each instance, up to the full cost of the proposed building and have been made for the acquisition of research laboratory space. In each of the grants made to date, the Administrator of the National Aeronautics and Space Administration has determined that the Nation's interests would best be served by investing title in the grantee.

Figure 14 shows the locations of these facilities. Figure 15 shows seven facilities that are nearing completion. In fact, six of them have reached the state that they are either partially or totally occupied.

One important consideration in the making of a research facilities grant is an agreement which culminates in the signing of a Memorandum of Understanding between NASA and the institution in question by the Administrator of NASA and the principal executive officer of the university which states in part:

> It is the policy of the National Aeronautics and Space Administration to support research in space-related science and technology at nonprofit scientific and educational institutions. Where additional research facilities are urgently needed to conduct such research in support of the national space effort, and the institution involved has demonstrated its intent to seek ways in which the benefits of this research can also be applied to the social, business, and economic structure of the United States, NASA may supplement research support with funds necessary for the construction of such facilities. The National Aeronautics and Space Administration is particularly desirous that the environment in which space research is conducted and its full benefits realized will be characterized by a multidisciplinary effort which draws upon creative minds from various branches of the sciences, technology, commerce and the arts. The desires of the university are in conformity with this policy, and the Institute intends to foster and conduct research in all areas of space-related sciences, bring to bear on this research the efforts characteristic of a major university, and seek ways in which both the direct and indirect benefits of such research can contribute to the economic, social and general well-being of the nation.

Table IV.—Summary of Research Facilities. March 1, 1965

Institution	Investigator/Topic	Area, gross sq ft	Amount, dollars
Fiscal year 1962			
RPI	Wiberley/materials research	59 800	1 500 000
Stanford	Lederberg/exobiology	14 500	535 000
Chicago	Simpson/space sciences	45 000	1 775 000
Iowa	Van Allen/physics and astron.	24 000	610 000
California (Berkeley)	Silver/space sciences	44 100	1 990 000
Harvard	Sweet/biomedicine	4 500	182 685
Fiscal year 1963			
Minnesota	Nier/physics	17 400	704 000
MIT	Harrington/space sciences	75 000	3 000 000
Colorado	Rense/astrophysics	31 800	792 000
UCLA	Libby/space sciences	68 500	2 000 000
Wisconsin	Hirschfelder/theor. chem	12 000	442 760
Michigan	Norman/space sciences	56 000	1 750 000
Pittsburgh	Halliday/space sciences	47 300	1 500 000
Princeton	Layton/propulsion sciences	26 300	625 000
Lowell Observ	Hall/planetary sciences	8 600	236 520
Fiscal year 1964			
Texas A & M	Wainerdi/space sciences	34 000	1 000 000
Maryland	Martin/space sciences	70 000	1 500 000
USC	Meehan/human centrifuge	4 000	160 000
Cornell	Gold/space sciences	38 000	1 350 000
Rice	Dessler/space sciences	68 000	1 600 000
Purdue	Zucrow/propulsion sciences	5 000	840 000
Washington (St. Louis)	Norberg/space sciences	24 600	600 000
New York	Ferri/aeronautics	21 000	582 000
Georgia Tech	Picha/space sciences and technology	50 000	1 000 000
Arizona	Kuiper/space sciences	50 000	1 200 000
Illinois	Alpert/space sciences	51 000	1 125 000
PIB	Bloom/aerospace sciences	16 000	632 000
TOTAL		966 400	29 231 965

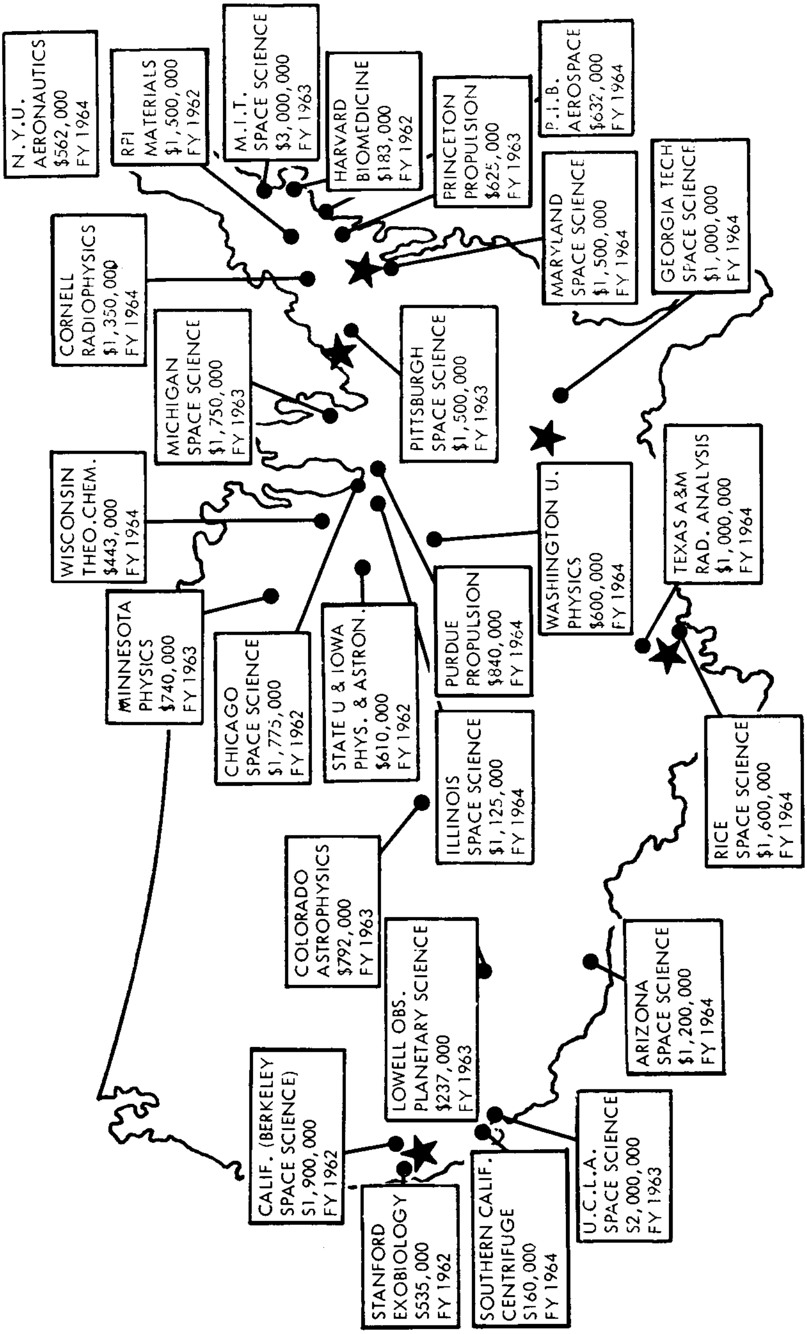
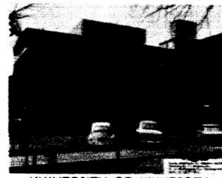


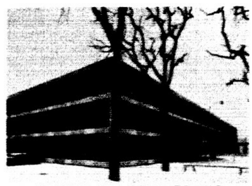
Figure 14.—Sustaining University Program research facilities.

PRINCETON UNIVERSITY
PROPULSION LABORATORIES

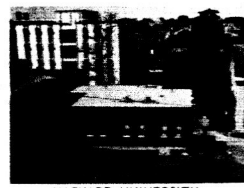


UNIVERSITY OF MINNESOTA
PHYSICS RESEARCH LABS

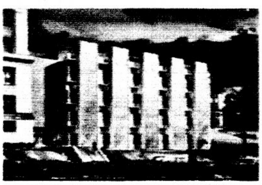
LOWELL OBSERVATORY
PLANETARY RESEARCH CENTER



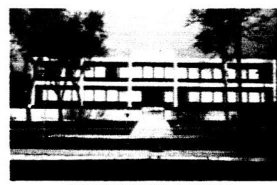
RENSSELAER POLYTECHNIC
INSTITUTE
MATERIALS RESEARCH
CENTER



HARVARD UNIVERSITY
BIO-MEDICAL ANNEX



UNIVERSITY OF PITTSBURGH
SPACE SCIENCES & COORDINATION CENTER



UNIVERSITY OF CHICAGO
SPACE SCIENCES LABORATORY

Figure 15.—Completed research facilities.

Of special significance is a portion of the last sentence which states that the university will ". . . seek ways in which both the direct and indirect benefits of such research can contribute to the economic, social, and general well-being of the nation." Implicit in this statement is our expectation that the university will go beyond the more conventional role of teaching, seeking new knowledge, and serving as the custodian of knowledge by seeking new ways to accelerate the flow of this knowledge to the community.

Discussion of this portion of the Memorandum of Understanding touches on only one aspect of the whole subject of technology utilization. In such a large scientific and technological endeavor as the space program NASA would be delinquent in its responsibilities if it did not make a concerted effort to see that the knowledge brought about by this program serves not only the interests of the program itself but is usefully applied to improving national welfare. To this end, NASA several years ago established its Office of Technology Utilization. The program of this office involves NASA, the universities, industry, and the community. The universities are playing an ever-increasing role in seeking new ways to speed recently acquired scientific and technological space information into other areas where it may be used.

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The Sustaining University Program has been designed as an integrated program encompassing the support of training, research, and research facilities in a manner that will augment and complement sponsored project research and in-house activity in support of NASA's mission. We consider it essential to develop a strong, mutually interdependent relationship between NASA and the universities in working to fulfill the needs for scientific manpower and research in the Nation's space program. It is our belief that within the universities rests the competence, imagination, leadership, and integrity that are essential for the conduct of these activities of mutual interest. As long as the universities demonstrate that they are able to carry on these activities in a creative and responsible manner, NASA will strive to maintain the broad liberal approach that we believe is self-evident in the NASA University program.

N66-12403

The NASA Space Science and Applications Program

Homer E. Newell

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SPACE SCIENCE AND APPLICATIONS, NASA

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION'S PROGRAM is a very broad one. It includes basic science, the advancement of technology, the application of space knowledge and technology to practical uses, and the development of manned space flight. Dr. Bisplinghoff will report on the applied research and technology program. Dr. Phillips discusses in a subsequent paper the manned space flight effort, including the Gemini and Apollo programs. My paper concerns space science and applications.

The National Aeronautics and Space Administration was established in the early days of what we have come to call the Space Age. There were many motivations behind the creation of NASA, but they can all be summarized in the intent to establish and maintain this country in a strong position in the Space Age. To this end we have undertaken to develop a broad space capability that will secure to this nation strength, security, flexibility, and freedom of choice in space matters. An essential part of this effort is a vigorous program in the use of rockets and spacecraft to advance human knowledge of the Earth and space, and to develop practical space applications.

In this endeavor, the space science and applications program has achieved 54 successful satellite and space probe flights since the start of the effort a half dozen years ago. In addition, hundreds of successful sounding rocket flights, balloon borne and aircraft experiments, ground observations, laboratory research, and theoretical work serve to round out the effort, and to establish close ties between the space flight program and related ground-based activities. Such close ties are essential if the space flight effort is to be viable and productive.

Of the 54 successful space flight and applications missions, 32 were scientific satellites, 18 were applications satellites, and 5 were successful deep space probes.

The program began with the modest Explorer type satellites. With the passage of time, the spacecraft and missions increased in complexity. Tiros, Nimbus, Syncom, Ranger, the Orbiting Solar Observatory, Mariner, the Orbiting Geophysical Observatory, and others, are highly sophisticated spacecraft, the successes of which indicate a distinct maturing of our capabilities in space. The year 1964, for example, was a very productive one, including such important missions as Ranger VII, Nimbus, Syncom III, OGO I, Centaur, and Mariner IV.

These successes indicate achievement and progress. They tell us that our space effort is no longer a program with only a promise for the future. They assure us that our effort enjoys a creditable past, a very active present, as well as a bright promise for the future. But they also stimulate us to ask: "Success at What?" "Progress Toward What?" This is what I should like to review.

In the area of space applications, our overall objective is to wrest maximum practical benefit from our developing space capabilities. In this endeavor we have achieved significant success in several areas.

The Tiros program with its nine successes developed both the basic spacecraft technology and the sensors which will be used on our first operational weather satellite system, TOS, an acronym for Tiros Operational Satellite. Both the Tiros and Nimbus weather satellite projects are producing the necessary sensors for use in the operational system. Sensors and systems which have been tested to date have provided (1) full global cloud cover data, (2) automatic picture transmission of daytime cloud cover data to local users, (3) infrared measurements of nighttime cloud cover, and (4) infrared radiometer measurements of the Earth's heat balance. Command and data acquisition stations, communications links, and data processing techniques have been developed in order to permit the U.S. Weather Bureau to utilize the satellite information in a timely manner in its routine weather analysis and forecasting operations. The space program is, in fact, playing an important role in providing the global data gathering capability needed to match advancing theory, moving us rapidly closer to the day when successful long-range weather forecasting will be possible.

Similarly, the Echo, Telstar, Relay, and Syncom satellites have served to lay the initial groundwork for the development of an operational communications satellite system. Building on this groundwork, the Communications Satellite Corporation is now moving ahead with plans for a commercial operational system.

It should be noted here that NASA does not plan to assume operational responsibilities in either the meteorological or communications satellite areas. In both areas, NASA has been fulfilling its responsibility of performing the necessary research and development in space technology and advanced sensor concepts, which is not only advancing the state-of-the-art, but is also contributing to improvements in the operational capability. The U.S. Weather Bureau, of the Department of Commerce, will manage and operate the U.S. Operational Weather Satellite System. Similarly, the operating agency for Commercial Communications Satellite Systems is the Communications Satellite Corporation established by the United States Congress for this very purpose. In both cases, NASA will play a supporting role providing such essential services as launching the spacecraft, and tracking and monitoring the spacecraft in orbit as required. NASA will also conduct a continuing R&D program leading to low cost, longer life, and highly reliable operational systems.

NASA continues to search for other potential applications of space technology. We are continuing to develop the technology for weather satellite systems, including advanced sensors, improved control and stabilization systems, longer life power sources such as a radioisotope thermoelectric generator, and systems which can handle increased amounts of data at a more rapid pace. We are investigating the feasibility of synchronous meteorological satellites to provide more frequent observations of areas of rapid weather changes. We are attacking vigorously the problem of measuring the vertical atmospheric structure both by means of sensors aboard the satellite and by a satellite data collection subsystem to interrogate and locate instrumented platforms in the atmosphere and on the ground. We feel certain that these efforts will do much to meet the requirements of our data-hungry numerical weather predictors.

As an extension of the communications satellite technology, navigational satellites may have important commercial applications. In conjunction with other interested agencies, NASA is investigating these possibilities, with especial attention to the problem of contributing to air traffic control and safety.

The space science part of the NASA program began with the momentum contributed by the International Geophysical Year, which saw the launching of the first Explorer and Vanguard satellites. As mentioned previously, space science is not separate from the rest of science, but rather is an extension made possible by the availability of rockets, satellites, and deep-space probes. This is such an important point that it may be well to illustrate the point by a brief review of how the space program is impacting upon various disciplines of science.

Because of the space program, geophysics is experiencing a tremendous broadening of its horizons. On the one hand the geophysicist finds in the satellite a new tool for investigating classical problems, such as the figure, structure, and atmosphere of the Earth. In addition, the geophysicist finds exciting new problems to tackle, such as the Van Allen radiation belts and the Earth's magnetosphere. Moreover, geophysics is being carried forward to new domains, as instruments reach the Moon and the planets, giving to the discipline a perspective that it could never achieve as long as geophysics was confined to a single body of the solar system.

Similarly, the space program is giving a new dimension to astronomy. The ability to observe above the filtering, distorting atmosphere in wavelengths not hitherto observable promises exciting new discoveries. The potential value of this opening up of the observable spectrum is indicated by the very theory that astronomy has developed from ground-based optical observations. That this is no empty promise is already borne out by the early observations by means of sounding rockets in both the ultraviolet and X-ray wavelengths. Particularly exciting is the discovery of some 10 sources of X-ray radiations in the depths of our galaxy. Because of the importance of astronomical data to the field of cosmogony, the intellectual potential of satellite astronomy is very exciting.

The field of physics finds in the region of outer space a laboratory of challenging opportunity. In interplanetary space, matter and fields exist under conditions unobtainable in the laboratory on the ground. The solar wind, solar cosmic rays and magnetic fields, their interaction with the Earth's magnetosphere, and similar phenomena give the physicist an unexcelled opportunity to extend his studies of plasmas and magnetohydrodynamics. The very high energy end of the cosmic ray spectrum is available as a source of particles for investigating interactions with matter of particles with energies far above those obtainable in accelerators presently available. Also, in the future, manned orbiting stations will provide the opportunity to conduct controlled experiments under space conditions. What this may mean to physics is not yet clear, but now is the time to think through the full implications of this opportunity.

It is, indeed, interesting to observe that one of the impacts of space efforts on physics, geophysics, and astronomy has been to draw the three disciplines together more closely than they have been drawn together in the past. In the investigation of Sun-Earth relationships, a most complex and challenging area of investigation, all three of these disciplines find themselves in partnership on problems of common interest. The same may be said of the broader problem of investigation of the solar system.

The impact of the space program on bioscience is still developing. Nevertheless, there appears to be much of promise in the space program for the bioscientist. Of particular importance is the area of exobiology; that is, the search for and study of extraterrestrial life. Should life be discovered on Mars, this will be an exceedingly exciting event in the space program. Even if life is not discovered on Mars, however, the investigation of the chemistry of the planet, particularly of how far that chemistry may have progressed toward the ultimate development of life, will be of interest and importance. Finally, in near-Earth satellites, there will be the opportunity to study living material under the conditions of outer space. Of particular significance will be the condition of weightlessness, and the removal of the living organisms from the normal periodicities experienced at the surface of the Earth.

The satellites, space probe, and manned spacecraft give the scientist a new approach to the solution of many important problems. They serve to strengthen his hand—if used effectively. But that is the important point. These tools are only as useful as they are made to be. The requirement is for competent people.

The space program requires highly trained and competent scientists and engineers to carry it forward to success. In order to maintain a viable program it is necessary that top-level technical people be interested and involved in the effort.

At the present time, about 58 000 people are involved in NASA's space science and applications program. Of these, 15 000 are scientists and engineers. During the past year, almost 700 were leading scientists serving as principal investigators and co-investigators in the national space program on about 2000 separate supporting research and flight experiment tasks in various disciplines of space science and applications.

In the area of applications, the emphasis is on industrial participation, although university participation is significant. In contrast, space science places its greatest demand on the universities. Indeed, in the space science area, NASA regards the resources made available to it as a national trust, to be managed in such a way as to draw from our national capability the very best of which the country is capable. We have felt that the most effective way in which to do this is to carry out the program in a way that strengthens the universities and other groups participating in the program.

Of particular importance, since basic science is one of our main areas of concern, we hold it imperative that we support the participation of scientists and scientific groups in such a way as to preserve the integrity of science.

Twice a year we issue a document describing the opportunities available to the Nation to carry out experiments on satellites and deep-space probes. We emphasize that these opportunities are opportunities for scientists to pursue their ideas in solving problems which they judge to be of scientific importance. A mutuality of interest is prerequisite, and we must, of course, undertake to pull together payloads that make sense in toto; but when we accept a proposal to carry out a space experiment, we do contract to support the investigator in such a way as to preserve the validity and integrity of his experiment.

Whenever possible we support space research in association with the teaching of new talent. Indeed, it is our contention that the best research is fostered by the teaching of competent young men who have a talent for asking disconcertingly penetrating questions of their professors.

We recognize that the conduct of experiments in satellites and space probes in not easy. We recognize further that it tends to create special problems for universities and colleges. Nevertheless, we insist that there are important benefits to science and education in participating in satellite and space probe programs. To help profit by these opportunities, NASA undertakes to provide universities that do not wish to do their own enginering with engineering support for the preparation of flight experiments. This support may be provided directly by a NASA Center, or funds may be included in the grant to the university so that an engineering contractor may be hired.

NASA also recognizes the need to assume some share of the burden of supporting, in a general way, research in the areas pertinent to the NASA program. Although we do not support as much of this broader type of activity as many would like to see supported by NASA, nevertheless NASA does contribute significantly. Our program offices do support a sizeable amount of ground-based and laboratory research, and theoretical studies, occasionally providing special instruments, such as telescopes, radio antennas, computers, and laboratory equipment.

In addition, our Sustaining University Program provides for support of the training of predoctoral students, some research laboratory buildings, broad multidisciplinary research grants, seed-type grants, and assistance in developing a space capability. These university activities are illustrated in full measure in the papers presented herein. There is, therefore, no need for me to dwell on the various elements of the program. I would, however, like to emphasize certain important points.

NASA policy encourages long-term funding, which gets away from the year-by-year frantic scramble to obtain renewed support for work of a continuing nature.

We also encourage placing responsibility in the hands of the university when that is where the responsibility really belongs. For example, the university is best able to select those students who should receive training fellowships; therefore, we do not attempt to make such selections in Washington at NASA Headquarters, but rather place that responsibility in the hands of the university administration. As another example, the broad multidisciplinary grants awarded by NASA are designed to give the university flexibility in placing these resources where they will do the most good.

NASA insists on open publication of results obtained by scientists participating in the NASA program. We require that these results be published in the scientific literature appropriate to the particular discipline concerned and that they be presented at meetings of scientific societies and at pertinent symposia.

NASA also seeks the advice of the scientific community in establishing the scientific objectives of its flight missions, and in selecting the experimenters and investigators for the program.

In summary, NASA's space science program has been designed to enable the scientific community—in particular the universities and colleges—to undertake the solving of scientific problems, of challenge and importance, in the manner of good proven scientific tradition. This approach is designed to uphold the integrity of science and scientists.

In view of the considerable discussion of this question of the integrity of science that has been held of late, I think it of especial importance to emphasize this point. In fact, I would like to go a little further. A recent report has deplored the fact that the scientific method was not used in arriving at certain far-reaching national decisions in connection with such things as nuclear testing, nuclear explosions in space, the use of insecticides, communications experiments in space, and the Apollo lunar landing program. My intention here is not to argue with the merits or demerits of those decisions, but rather to point to a potential danger to the integrity of science if scientists themselves fail to be clear about where the scientific method is applicable, and where it is not.

There is no need for me to describe the scientific method in detail. Let me, therefore, simply emphasize one aspect. The scientific method is adjudged valid for science because it is assumed that there is a basic truth that serves as a guide to the process of information exchange, debate, thought, and analysis. This underlying truth, though it may not be seen or understood at the moment, implies that there is an answer to the question under consideration and that at the moment there probably exists a best answer on the basis of all the data and information available.

In the complex matters of the social, political, and economic problems, it cannot be assumed that there is any best answer to a problem under consideration. Indeed, there may be many acceptable solutions, among which a choice has to be made with due consideration to various possible tradeoffs and intangible factors that have a bearing. Success in the solution of a problem often depends on the intuitive power, foresight, and imagination of individuals in a position to make a decision.

In such situations, the scientific method cannot be expected to be the sole guide to the final decision. The scientific method can be useful in providing for an orderly approach, for exposing important issues to open debate, for bringing to bear many able minds on a problem that deserves wide-spread attention and thought, and, in particular, for clarifying and sharpening any scientific issues that may be involved. However, even though some of these matters may involve or impact on science and scientists to a considerable degree, in total perspective there are other issues and questions to be considered, and these other considerations may in many cases be overriding.

The point that I am trying to bring out here is that it is important for scientists to recognize the limitations of the applicability of the scientific method. Failure to recognize these limitations can only lead to much confusion and is in itself a potential danger to the integrity of science.

In concluding, let me, then, repeat a statement I made 2 years ago, and for which I have since been criticized. The overall space program has many motivations, including, in addition to science, matters of national leadership and prestige, national strength and security, advancing technology, potential economic payoffs, and practical benefits. Thus, while some of the objectives of the space program are scientific, many are not. This move out into space is a tremendous human venture and adventure. It is a challenge to the spirit of man that our Nation, with its tradition of leadership and forward moving, cannot fail to accept. We should be ashamed as a Nation if we did not rise to the spirit of this venture and move forward with vigor and determination.

But we have taken up the challenge. We are moving forward vigorously and with determination; and we are doing this, as I have said, for many reasons that are not science. But what about science? I contend that since the space program is going to move ahead, since we are going to follow through on the Apollo lunar landing program, since we are going to develop a national space capability, then it behooves us as a responsible nation to see to it that our space program contains the very best science of which this country is capable.

I contend that this is a challenge to the scientific community to rise to the occasion and see to it that good science is carried out in all of our spacecraft and deep-space probes, both unmanned and manned. This is a challenge which the scientific community can lose by default, since the sense of responsibility of those responsible for the space program will lead them to do whatever science they can achieve in this program. If the responsible and competent elements of the scientific community are not involved in each and every element of the space program, then the science will not be the best that it could be. If the scientific community is properly involved, then the scientific results of the program can be the shining jewel of our space effort.

The responsibility for fashioning this jewel rests in large measure on our universities and colleges.

NASA's Program in Advanced Research and Technology

Raymond L. Bisplinghoff

ASSOCIATE ADMINISTRATOR FOR

ADVANCED RESEARCH AND TECHNOLOGY, NASA

THE MOST CONCISE REASON I can give for having an advanced research and technology program is that preeminence in aeronautics and space will depend not only on current aeronautical and space operations, but also on our ability to organize and extend the underlying body of science and technology. The instruments by which this program is carried out are the five NASA research centers. They are the Langley, Ames, Lewis, Flight, and Electronics Research Centers. Resources amounting to about 10 percent of the NASA budget are invested in advanced research and technology.

Although NASA's program of advanced research and technology is dedicated to preeminence in atmospheric as well as in space flight, I shall confine my remarks largely to space.

In assessing the technologies of space flight, we might view them in three steps: from Earth to Earth orbit; from Earth orbit to Moon; and from Moon to planets. The steps in space from Earth to Earth orbit and from Earth orbit to Moon rest on essentially the same technologies. They are familiar: chemical energy conversion, relatively common engineering materials, guidance and control components generally consistent with aircraft and ground applications, and microwave communications. However, the step from Moon to planets demands performance and reliability measured in orders of magnitude beyond the previous steps. New levels of technology clearly are needed. In a nutshell, NASA's advanced research and technology program is devoted to improving the reliability of all three steps and in conceiving and developing the new concepts required for the third step. I would like to discuss the third step.

There is first the field of energy conversion. Chemical rocketry, which has formed the basis for the space program so far, will continue to serve in important ways on planetary missions. The principal new requirements for deep space applications are fuels with high specific impulse and density capable of long duration storage with little loss. Oxidizer-fuel combinations such as oxygen-difluoride and diborane, oxygen difluoride-hydrogen, or ammonia-hydrazine mixtures are examples which we are now studying. During the past year we have been operating a rocket engine using a fluorine and hydrogen propellant combination. This work marks the culmination of over 15 years of research by universities, government laboratories, and industry on the oxidizer fluorine.

But chemical rocket efficiencies are marginal for manned missions to the planets where prodigious amounts of total energy are required. It is clear that the deep penetration of space with large payloads for long periods of time will require nuclear energy.

Using the solid graphite core nuclear rocket technology now under development in the Nerva program, it should be possible to perform the manned Mars mission at any opportunity with sufficient growth potential for extended exploration of that planet.

A nuclear third-stage Saturn V employing the same technology could provide the capacity for performing unmanned missions to explore the space environment very close to the Sun, at long distances from the plane of the ecliptic, as well as the placing of large payloads in orbits around Venus, Mars, and Jupiter. For such missions, the nuclear stage could be augmented by a high energy kick stage or by electrical propulsion to achieve the extremely high velocities desired.

Like the chemical rocket, the key to nuclear rocket efficiency lies in the heating to high temperatures of a low molecular weight gas. In concept we may expect to achieve gas temperatures of the order of 5000° F with graphite or tungsten fuel elements operating for short periods of time. The past year saw the successful testing at high power and high temperature of three reactors in the nuclear rocket program. Powers of over 1000 megawatts were achieved, giving a space equivalent performance of some 57,000 pounds of thrust and 765 seconds of specific impulse. These tests demonstrated for the first time that nuclear rockets can achieve the high performance that has been predicted for them.

The principal barrier to higher temperature operation is a materials problem—maintenance of fuel element integrity for the desired engine life. It is therefore important in looking to the future to discover new concepts of containment which will allow us to transcend materials limitation. Gaseous containment of the fission process is conceptually possible and it would, if it could be devised, permit propellant temperatures an order of magnitude greater than those of solid core reactors. Although our research in this area during the past year was promising enough to continue, I cannot report major steps toward a solution.

During the past year, resolution was achieved of a basic uncertainty over the feasibility of ion propulsion for deep space applications. In the Sert I flight, launched from Wallops Island last summer, the United States conducted the first successful flight test of an ion engine. During this flight an ion engine was operated with and without electrons injected into the exhaust stream to determine whether the electrical charge in the exhaust could be neutralized. This question could not be resolved completely by ground tests because of the unknown influence of the test chamber walls on the results. The flight conclusively demonstrated that neutralization can be achieved in space. It also demonstrated that the performance of an electric engine in space can be closely correlated with the data obtained from ground tests.

Although chemical and solar power will be used in selective applications to planetary missions, the generation of large quantities of electrical power for long periods of time in space will rest eventually upon nuclear energy. In contrast to high acceleration nuclear rockets, electric power reactors will operate for long periods of time at somewhat lower temperatures. Low specific weight, high reliability, and long life are necessary requirements. Liquid metal turboelectric systems employing a Rankine cycle match present reactor technology During the past year, we succeeded in testing for the first time the principal component of the Snap 8, a 35 kW nuclear-electric system. These components ran together in a loop for approximately 100 hours before the test was halted to permit inspection of parts. Our research during the past year also involved thermoelectric, thermionic, Brayton cycle, and MHD energy converters. The use of an MHD device, linked with gaseous containment of the fission process, can be visualized as an attractive future step.

The demands on materials of the step from Moon to planets are exceptionally severe. Materials are required that will retain their mechanical properties for thousands of hours, will not burn or oxidize, will remain compatible with new propellants, and will be stable in the presence of the high vacuum and solar radiation of space. We must face the possibility that future space missions will be severely compromised if not impossible without new and better materials. Whether such materials will appear depends on our progress in achieving a fuller understanding of the forces and energy states bonding nuclei together in solids.

In the meantime, our recent progress in improving the temperature capabilities of materials has been encouraging. For example, during the past year, through NASA-sponsored research, the limit of usefulness of polymer film was raised from about 750° to 1100° F and the temperature limits of thermal insulation foams was roughly doubled from 2000° to 4000° F.

Along with energy conversion and materials, the process of measuring or sensing and then using the data obtained to control the flow of energy has evolved as one of the most important branches of space technology. The first nonhuman feedback control device was probably the flyball governor used to control the gap between the stone burrs of water-driven flour mills. In 1924 Minorsky constructed a servodevice which was installed on the battleship New Mexico to steer it automatically across the Gulf Stream much as we steer a booster through the shear layer in the lower atmosphere. However, man provided such an efficient combination of sensor, feed-back device, and muscular control system that it was not necessary to find substitutes until the last three decades. But, the dynamic response of man as measured by his bandwidth is limited to the range of 0.5 to 1.0 cps. Changes in his role were required when aircraft and fire control systems demanded responses beyond his bandwidth capability and when unmanned aircraft and missiles appeared.

In looking toward the future demands of space systems on this branch of technology we find several areas where a significant increase in capability is demanded. Among these are precise pointing and attitude requirements. For example, the gain-bandwidth efficiency of a synchronous communications satellite is directly affected by the accuracy with which the antenna can be pointed. Although vernier-controlled small propulsion devices are essential to high pointing accuracy, the most critical element is the sensing device itself.

The accuracy required of these devices must be about an order of magnitude greater than that for the overall stabilized system. Sensors for pointing accuracies from 1 to 0.1 degree are within our grasp. However, solar observatory requirements will require 10^{-3} degrees and laser communications and long range astronomical requirements will approach 10^{-5} degree. Although star and solar sensors can be used to obtain very precise pointing information, horizon sensing is a more simple and direct method of attitude reference for orbiting spacecraft. The accuracy of horizon sensors has been in the neighborhood of 1 to 2 degrees using infrared. The use of physical phenomena other than infrared may be required to obtain the accuracies up to 10^{-3} degree which will be required for mapping, scientific data gathering, and for minimizing communication power. Visible airglow, ultraviolet radiation, and radiofrequency radiation are all possible phenomena for achieving this end.

Fundamental to all man's undertakings is his ability to communicate rapidly with precision. One measure of our ability to communicate is the number of bits of information that can be transmitted per unit time. Today, we recognize that about 5000 bits per second must be transmitted for intelligible voice communication and some 10 to 100 million bits per second for high quality television. Such rates are achievable with today's technology between points on the Earth's surface and near space. However, at the heart of the difficulty of extending this capability to deep space lies the fact that the data rate capability for a given system varies inversely with the square of the distance between transmitter and antenna. For example, the capability of the Mariner system transmitting from Mars is only of the order of one bit each 5 seconds. The data rate of microwave systems may be increased by increasing operating frequency, antenna aperture, and power and by decreasing inherent noise in receiving systems. Improvements of this kind, including the use of 2300 Mc frequencies and 210-foot antennas, may permit the Mars to Earth capability of the Mariner system to be raised to some 1000 to 5000 bits per second in the early 1970's. This is, however, far short of that needed for real time television. It is questionable whether conventional microwave techniques can be stretched to the extent of providing real time television from Mars, in which case millimeter wave or optical communication systems must be developed.

Within the past few months, the first space flight experiments were conducted on the use of lasers for communications and tracking. The Explorer XXII satellite, now in orbit, is equipped with corner reflectors designed to reflect a laser beam transmitted from the ground back along its original path. Tracking is accomplished through a computer which alines the laser beam with the predicted satellite position. The laser pulse starts a counter that is stopped when the reflected pulse is received. Tracking in this country has been achieved so far by the Goddard Space Flight Center, the Air Force's Cambridge Research Laboratory, and the General Electric Company.

During the past year, about 10 percent of the R&D funds in the Advanced Research and Technology program was invested in the university component of our work. The area of reentry technology is one that comes to mind when one considers this mode of employment of our nation's resources. The problem of aerodynamic heating during reentry has attracted much interest not only for its big role in missile and space technology, but also because it stretches the boundaries of our knowledge in aerodynamics, gas dynamics, heat transfer, and materials. The history of reentry technology shows the interact-

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ing and interwoven contributions of universities, industry, and government laboratories. During the past year, our programs led by the Langley, Ames, and Flight Research Centers involved the active participation of eleven universities and eight industrial firms. This work covered not only reentry into the Earth's atmosphere but the problems to be faced for entry into the Mars and Venus atmospheres as well.

And where does this technology stand today? We can say with certainty that Earth orbital return and lunar return speeds are well in hand. During the past year, the Langley Research Center successfully completed the fastest controlled reentry experiment yet conducted. The Project Fire spacecraft reentered the Earth's atmosphere at 37 000 feet/second. The principal purpose of this experiment was to obtain anchor data points on convective and radiative heat transfer in flight to confirm the credibility of ground experiments in ballistic ranges and shock tubes. We find that at these speeds there is reasonable agreement between prediction based on ground experiments and flight data. A second Fire experiment is scheduled. But much work in heat transfer, materials, and configuration studies remains before we will have mastered the technology of unbraked reentry from the planets Mars and Venus. The principal obstacle to an understanding of entry into the atmosphere of the planets is knowledge of their atmospheres.

I am convinced that if we wish to achieve success in our assault on the planets, the university research contributions must be increased. I refer here not so much to quantity as I do to the quality of these contributions. Let us take, for example, the matter of reliability. In planetary exploration, reliable operation will be demanded for thousands of hours of continuous, perhaps unattended, operation in space. We seek reliabilities well beyond anything achieved in complex systems on Earth. Can it be done? Perhaps a more appropriate question is, when can it be done? The kinds of reliabilities we seek will never be achieved by the technique of cut and try—of building and testing many objects and then drawing statistical conclusions. They will be achieved only by a rededication to the principles of simplicity of design combined with depth of understanding of the underlying physical processes. The bases for many of these principles will come from the unhurried thought and the formation of ideas by individuals working as individuals in universities. I would urge universities to encourage the creative individual—not to force him into organizational patterns—to channel his thoughts away from scientific formalism toward true understanding. Perhaps we can find again new contributions akin to the treatment of the Navier-Stokes equations by Prandtl in his famous boundary layer theory.

Even though university research contributions are necessary to the survival of the space program I would have to say that your most important product is people. In the education of students, I would like to repeat an often heard question. How can we develop more effectively the creative and imaginative talents of our students? I have the uneasy feeling that the analytical formalism and relentless pressures of science and engineering education do more to destroy than sharpen these qualities. In a recent article in *Physics Today*, Professor Martin Klein of Case Institute of Technology related remarks made by Albert Einstein to his close friend Marcel Grossman after passing the diploma requirements at the Swiss Federal Institute of Technology. Einstein said,

> It had such a deterring effect upon me that after I had passed the final examination, I found the consideration of any scientific problem distasteful to me for an entire year. It is little short of a miracle that modern methods of instruction have not already completely strangled the holy curiosity of inquiry, because what this delicate little plant needs most, apart from initial stimulation, is freedom; without that it is surely destroyed . . . I believe that one could even deprive a healthy beast of prey of its voraciousness, if one could force it with a whip to eat continuously whether it were hungry or not.

Although these words refer to an earlier day they are uncomfortable words when one considers the stature of the speaker and the trend of our modern educational processes. They are especially uncomfortable to me when I think about the price that is yet to be exacted from our ingenuity in order to penetrate the far reaches of the solar system. I am sure that they deserve our most careful thought.

Research Opportunities in Manned Space Flight

Samuel C. Phillips

DIRECTOR, APOLLO PROGRAM OFFICE

OFFICE OF MANNED SPACE FLIGHT, NASA

In this presentation I would like to indicate some of the details of the technical challenge of Apollo, NASA's maned lunar landing program, and discuss briefly some of the ideas for exploiting Apollo capability by using the developed systems for a broad spectrum of space research and experimentation.

We, in NASA, are honored to have a close working relationship with the university community. We recognize the universities as the fountainhead of our national strength in science and technology. We value university counsel in our present undertakings. We are keenly aware of university leadership in the basic and applied research that is providing man with ever-increasing knowledge and understanding of himself and of his total environment. And we recognize and fully appreciate the paramount responsibility of the universities in providing in the Nation the succession of duly qualified men and women who will serve as our scientific and technical leaders of tomorrow—in government, in business, and in the university.

The relationships that NASA now has with the university community must be continued—but more than that, we both must exert every effort to expand communications; undoubtedly it will be to our mutual advantage to do so. Through this continuing and expanding interchange, we can more fully benefit from consideration and evaluation by the universities of our present and future programs and tasks. In return, such information and support that NASA might provide could assist in guiding some of the university research activities as well as provide students of the space sciences with the latest available data and with challenges in their field. In this period of rapid change, the sometimes sluggish channels that once sufficed for communication of scientific and technical demands to the university laboratory and classroom are no longer adequate. Ours must be a continuing joint attack on the frontiers of knowledge. I believe that it is in the area of space sciences research that we have a natural and logical opportunity for effecting an even closer association.

Since most of the details of the Apollo mission are familiar, we might consider the capabilities that the Apollo system and its extensions offer to the experimenter. But before doing so, I would like to discuss some of the reasons why a man is of value in space. What are man's attributes as a subsystem of a manned spacecraft system? He is a relatively lightweight, versatile, and mobile computer with intelligence, judgment, and the abilities to anticipate events and make decisions. He can translate perceived data into relevant information. He can correlate, systematize, and recognize patterns. He can communicate the information obtained through these abilities, selecting only those items needed.

But for these benefits, we must pay a price. We must build a spacecraft structure that will protect man from the space environment and provide for his comfort and safety. We must supply food, water, oxygen, and energy for the operation of equipment that fills these needs. We must remove poisons from the air he exhales and dispose of his other bodily wastes. To do all of these things, many pounds of payload must be set aside. The necessity for this additional payload increases the complexity of the spacecraft and the required launch vehicle power. Hence, it increases the cost. The question to be answered with respect to each space mission is whether the benefits provided by man's presence justify this additional expense.

For this discussion, let us classify man's abilities in four categories. Man is a sensor, a manipulator, an evaluator, and an investigator.

As a sensor, he adds little to automatic equipment in space—sometimes nothing at all. Instruments are available with greater abilities to see, hear, touch, measure temperature, smell, and perhaps even taste if that is required. For most purposes of pure sensing, therefore, instruments can operate effectively without the immediate presence of man. Man's role as a sensor was demonstrated several times on the Mercury flights. Perhaps the most dramatic occasion was when Astronaut Gordon Cooper was preparing to return to Earth at the conclusion of his day-and-a-half orbital mission in May 1963. The automatic attitude control system of Cooper's Faith 7 spacecraft malfunctioned and he was required to orient the spacecraft by manual control. As he was flying over China on his final approach, Cooper observed the lights of Shanghai shining through the clouds and thus was able to maintain his yaw angle for the firing of the retros on radio command from Astronaut John Glenn aboard a ship in the ocean south of Japan.

The second function of man in space is manipulation. On many of the X-15 and Mercury flights it has been demonstrated that a man can operate the spacecraft controls, as was done by Astronaut Cooper in Faith 7.

In the conduct of space science research, man manipulates to begin to employ and probe into his environment, making use of motor responses and verbal skills to carry out procedures, and to assemble, operate, and repair equipment for investigative purposes. For such a purpose, in addition to possessing manipulative skill, the astronaut must be able to describe clearly and concisely the situation, the changes that occur, and the responses to procedural changes recommended from the ground.

In manipulation, man in space moves from the passive role of sensor to active involvement with the environment, which enables him to overcome or bypass equipment failures in preplanned activities. The replacement of man by a robot manipulator would be extremely difficult—and the equipment would be subject to malfunction—but it would not be impossible.

In the areas of sensing and manipulation, the needs of science are being filled to a considerable degree in near space through unmanned satellites. We now have evidence in the Ranger VII and VIII photographs that lunar observations can be made with an unmanned spacecraft.

But as our explorations range deeper into the solar system, the speed of light places a limitation on our ability to manipulate on a real-time basis by remote control. A radio signal travels from the Earth to the Moon in about 1.3 seconds. Thus, a device on the Moon controlled remotely from the Earth cannot react to any situation in less than 2.6 seconds—the time required for a roundtrip radio signal. From more distant points, the radio relay time is proportionately longer, and the difficulty is increased.

When we move on to man's role as an evaluator, it is clear that his relative importance in the man-machine system is increased considerably. For sensing and manipulation, the human abilities to analyze, correlate, systematize, and select are valuable. For evaluation, they are essential. With the capacity to evaluate, the "sensing and manipulating" individual achieves a substantial degree of self-reliance in controlling what he perceives and how he reacts. When a man remembers, recalls, reflects, analyzes, compares, contrasts, and induces—when he understands, using a solid foundation of knowledge—he has improved the degree to which meaningful data can be translated into useful knowledge. To develop this evaluative ability, we are conducting a program of scientific education for the current astronauts, including instruction in astronomy, geology, and space physics.

The most advanced role of man in space is that of an investigator who responds creatively to unexpected situations, postulating theories and hypotheses and devising and initiating systematic measurements. In this role, the astronaut is a full-fledged scientist. It is to assure development of the capacity for this kind of astronaut involvement in space science investigations that we are engaged in a scientist-astronaut selection program. It is clear from this analysis of the functions of sensing, manipulating, evaluating, and investigating that man in space is valuable for the same reasons that man is valuable in scientific field studies or in the research laboratory.

Concurrently with our efforts in the Apollo program, NASA is conducting studies and planning missions utilizing Apollo developments for missions other than the initial manned lunar landing program. With Apollo equipment, for the first time we will have an opportunity to perform experiments that heretofore were too large, too complex, too heavy, or too power-consuming for other satellite programs. Initially, the basic Apollo spacecraft can be placed in a low Earth orbit by the Saturn I–B launch vehicle carrying experimental payloads of up to 2000 pounds with nearly 210 cubic feet of unpressurized volume available. The payload can be so configured that as much as 500 pounds of experimental data (film, apparatus, or specimens) can be returned to Earth and recovered for detailed examination and analysis. This orbiting system could achieve orbit durations of up to 4 weeks and could accommodate a three-man crew.

We can also plan on using the Apollo spacecraft in conjunction with the Saturn V launch vehicle. Capabilities can then be extended to meet the requirements for more demanding missions or longer orbit durations. For example, up to 90 days duration in Earth orbit can be obtained on Earth orbits of low inclination. Also it is possible to place the spacecraft in orbits offering unique viewing capabilities such as polar orbits or those at 23 000 miles altitude, in which the satellite revolves about the Earth every 24 hours and thus is synchronized with the Earth's rotation. The use of the lunar excursion module adds an additional 220 cubic feet of available pressurized volume for large dimension experiments requiring direct access by the in-flight experimenter.

The development of extravehicular operations will enable in-space assembly of experimental structures or apparatus too large or complex to be launched in an assembled condition. The absence of gravity allows theses structures to be extremely light and very large structures of precise dimensions are possible.

A manned station with these capabilities offers the opportunity to perform experiments in space science, in the development of Earth oriented applications, and in support of space exploration. Space science experiments can be conducted in astronomy, bioscience, physics, and chemistry. In the area of astronomy and astrophysics, an orbiting observatory would offer some attractive possibilities in that the spectral transparency and operational flexibility can significantly expand and extend our knowledge in this vital area.

In the bioscience area, experimentation and research can be conducted dealing with tissue regeneration and healing, bacteriology, germination, embryology, and cellular physiology. Such experiments in a zero gravity as well as other space environments could significantly enhance our understanding.

Experiments in the physics and chemistry area could include the study of basic physical processes such as surface tension effects, liquid/vapor interfaces and behavior in zero gravity, fracture mechanics, and the effects of long-term exposure of materials to the space environment on the formation of compounds, combustion, surface chemistry, and so forth. These physics and chemistry experiments will certainly contribute to the development of future spacecraft.

Recent advances in meteorological theories indicate that a synoptic, or overall, view of Earth cloud cover and knowledge of the interaction between extraterrestrial phenomena and the atmosphere can significantly aid in the prediction of weather. The unique viewing position from orbit using appropriate sensors can achieve the necessary worldwide synoptic coverage and can assist meteorologists in developing a more complete theory of the Earth's weather.

Another broad area that contains major research opportunities is that of Earth mapping survey. Subcategories under this broad area include geology, hydrology, agriculture and forestry, oceanography, and biogeography.

With the same Apollo Extension System concept we will be able to increase significantly our payloads sent to lunar orbit and to the lunar surface. The results obtained through a thorough investigation of the Moon could be far reaching in their implications. The past geologic history of the Moon is recorded permanently in an environment whose characteristics are such as to leave this record essentially undamaged and accessible. A detailed investigation of the lunar surface, subsurface, and the surrounding environment should reveal important facts about the origin of the Moon and its evolutionary process, hopefully shedding light on the origin of the Earth and possibly the solar system itself.

Suggestions and comments from the university community, not only with regard to research oriented endeavors but also with regard to any aspect of our program, are welcome. We are always interested in alternate and better approaches. As we continue to work together, as we learn to exploit each other's strengths more fully, we can move ahead confidently with a united and integrated approach in attacking the problems which lie before us on the very frontiers of technology.

The NASA University Program—A Two-Way Street

Stuart Symington

UNITED STATES SENATOR

LET ME EXPRESS APPRECIATION for the privilege of attending this NASA University Program Review Conference. It is rewarding to see major legislation such as the National Aeronautics and Space Act of 1958 carried onward and upward on a positive and tangible basis.

The program in which you are participating is a direct outgrowth of the will of the Administration, the Congress, and the American people. NASA's mission clearly includes "the expansion of human knowledge of phenomena in the atmosphere and space," and the "preservation of the role of the United States as a leader in aeronautical and space-related science and technology." Though not specifically named, university participation is implicit in both phases.

With that in mind, let us consider not what the universities are doing, or what NASA is doing, but what is being accomplished jointly—and what we hope may be accomplished in the years ahead. For it is my conviction that through continued and expanded efforts, the universities, the Government, and the industrial forces of the Nation will gain steadily from this program.

Today, we can take justifiable pride in the many space successes this Nation has achieved during the short 6½ years of NASA's existence. Within a period of little more than 4 years we have initiated, conducted, and completed with spectacular success our first man-in-space project, Project Mercury.

The manned flights began with the suborbital flights of Astronauts Shepard and Grissom, progressed through the three-orbit flights of Astronauts Glenn and Carpenter, moved on to the six-orbit mission of Astronaut Schirra, and culminated with the 34-hour, 22-orbit flight of Astronaut Cooper. Aside from the significant fact that these flights began before the third anniversary of NASA, the most noteworthy aspect is that we carried out all these pioneering expeditions with complete safety of all six astronauts. So far, the safest way to travel in world history is through space.

I hope and believe that the experience gained in Project Mercury will enable our scientists, engineers, and supporting personnel to make Project Gemini, our two-man missions, equally successful.

While we are making headway with the manned flight phase of the space program, we are also achieving dramatic results with the unmanned satellites and spacecraft. Meteorological systems Tiros and Nimbus advanced the state-of-the-art of weather forecasting through photographs of cloud formations, hurricanes, and typhoons. Likewise, the communications satellites Relay, Telstar, and Syncom proved the feasibility and practical worth of a satellite-based global communication system which will have major international value.

Concurrently, we are continuing to demonstrate our ability to explore the mysteries of space through such programs as Ranger, Mariner, and the Explorer series. Ranger VII traveled about a quarter of a million miles through space and provided our scientists and engineers with over 4000 pictures of the lunar surface before impacting on the Moon. Ranger VIII, following a similar path, provided more than 7000 more Moon surface pictures, this time of another area—as with Ranger VII, a landing site that was determined to be the target in advance of the flight. Not only did Ranger VIII give spectacular pictures, it actually hit the Moon within 15 miles of the planned point of impact, this after a flight of 248 766 miles. The Mariner Venus and Mars flights represent another spectacular and successful area of effort.

We can be proud of these successes and of our progress in other related fields, perhaps particularly the development of the Saturn I launch vehicle. All tests of this launch vehicle have been successful. A recent test, in addition to further proving the effectiveness and reliability of the vehicle, placed in orbit a vehicle known as Pegasus, a wing-shaped satellite designed to investigate meteoroids in space.

In other areas of research we are making sound progress in our manned lunar exploration program, in the design and development of more sophisticated guidance and sensing systems for use aboard spacecraft, and in the application of newly acquired technology to even more advanced projects than those now underway. Although still very much in the pioneering stage, we are rapidly gaining that experience and confidence which is necessary for the more ambitious undertakings of the years and decades to come.

A sobering thought presents itself, however. Let us consider where we are now and relate our present level of advancement to future expectations. Thus far, we have proceeded almost entirely on the strength of relatively old knowledge. The principles, the concepts, and in many cases even the technologies themselves were already in hand. We have been able to apply and exploit them because, for the first time in man's history, we have the tools to do so. Conditions will become markedly more difficult as we move beyond our first steps to undertake the ambitious goals and objectives inherent in the broader scope of the space age challenge.

It has been said before but it bears repeating: New knowledge, new technology, and more profound discoveries are prerequisite to the space role we envision for ourselves in the future. To put it another way: If this Nation is to achieve and maintain preeminence in space, we must widen the scope of man's imagination, trample roughshod over intellectually inhibiting barriers, and stimulate to their fullest potential the mental powers of young, and reasonably young, Americans.

The Government cannot do this alone. The universities cannot do it alone. And the industrial complex of this Nation cannot do it alone. It requires a three-force effort, but it will in the longrun produce three-way benefits.

In essence, that is what this conference is all about.

The force which the Government brings to this responsibility is uniquely "ungovernmental" in its concept and application. Whereas the traditional Government practice might be to enmesh a Federally funded program with a net of guidelines, restrictions, and directions, the NASA University program strives to give full play to local voluntary initiative. The Sustaining University Program's training and research activities encourage participation and provide support. Any requirement for universities to become engaged in the program stems from their basic yet paramount responsibility to the Nation to expand *all* fields of knowledge and assure its transmission to succeeding generations.

NASA does not predetermine which schools will participate in this program, nor does it select the predoctoral trainees, specify training curriculums, or undertake local administration of an individual university's participation. Rather, it evaluates submitted proposals and makes its selection on the basis of realistic criteria which take into account the school's overall competence, capabilities, and needs. Once it make a selection, it provides continuity of support, an essential ingredient for a program of this kind. Every training grant includes an allowance to the university with which it can strengthen its graduate program in space-related areas of science and technology. Throughout the program, NASA's motivations are of necessity geared to its space mission. The predoctoral training activity, for instance, was designed to accelerate the production of Ph. D. degrees in space-related science and engineering.

Similarly, through the research component, NASA seeks to derive vigorous, creative, and productive contributions to specific areas of scientific research and technology. Far from surrounding its university relationship with defining and restricting conditions, however, in this particular venture NASA seeks to help preserve for the university its freedom of decision. This very absence of binding definitions and presumptious regulations results in placing the university space-age responsibility where it properly belongs—in the able hands of university administrators, professors, researchers, and dedicated graduate students.

Perhaps it would be appropriate to refer to a major consideration which emphasis on the term "space age" may cause us to overlook. The Nation's space program is *not* the root cause, but the effect, of expanding scientific knowledge and technology. Scientists and other researchers the world over continue to generate great masses of new knowledge, and universities continue to face the increasingly difficult task, the challenging requirement of introducing this new knowledge into laboratories and lecture halls. We must not look upon the drive for dramatically new scientific knowhow as only an expedient aimed at achieving political purposes, worthy as those purposes may be. Rather, we must view it for what it truly is—the clear-cut extension of man's burning desire to know more and do more.

While successfully accomplished space missions provide direction and reward for this desire, we can be assured that as long as man survives on this planet he will have questions; and as long as he has questions, he will look for answers. This will be as true after the voyage to the Moon as it was before the voyage to America.

Now, let us consider for a moment the special force the universities bring to bear on this effort and what their participation means, both to them as institutions and to the society they serve.

As is well known, the democratic structure of our society continually places pressure on our universities to tap new sources of knowledge, to process that knowledge and identify areas of application, and to assure its injection into the Nation through trained individuals.

Our universities are not merely a desirable appendage to community life. Rather, they are at the very center of its development and must work as an integral and dynamic force within it. More specifically, the scientific and engineering aspects of universities, particularly at the graduate level, are now at the center of future community—and national—welfare. From them must come the future leaders of science and technology, as well as a vast portion of the ideas demanded by the technological revolution in general and the space program in particular. Through their participation in the NASA University programs, universities are helping to channel new ideas, new scientific and technical solutions, and more highly developed brainpower into the space effort. By so doing, they assist in satisfying the Government's selfish interest in the program—in justifying its cost to NASA and to the American taxpayers.

Further, and I think this most important as far as our total national welfare is concerned, they are placing themselves in a better position to serve one of their major functions: that of providing even greater support to the industrial complex at large and to the local community of which they are a part. In this regard, transmission of knowledge must extend beyond the limits of classroom and laboratory teaching. As new discoveries are made and new technology developed, it is incumbent on the universities to develop more rapid means of communicating such information to industry and the community.

This rapidity is imperative because of the growing need to compress the research-to-development-to-engineering-to-exploitation cycle. About half of what an engineer knows today will be obsolete in a decade or so, and about half of what he may need to know in 1975 is not available to him now. Unless today's working scientists and engineers are kept current on what is new, their potential for continuous productivity will deteriorate. Similiarly, the economic health of individual industries is increasingly dependent on the up-to-dateness of their methods and processes.

Of course, the universities themselves will gain through participation in this program. They have the opportunity to strengthen their own areas of space-related work, and within their own facilities and capabilities, stimulate development of new ideas and talent. Furthermore, these plans and programs should encourage researchers and faculty members to remain with their institutions, and thus create and maintain a nucleus which will attract highly motivated young people towards graduate studies. Such a self-serving prospect should be a particularly strong incentive, especially for those colleges and universities that wish to strengthen certain areas of endeavor.

The third force, the force of industry, is less directly involved in the specifics of this conference than the university. But it, too, has a responsibility to support the NASA University Program—and an opportunity to gain a great deal from it. There is a growing need for closer liaison between industry and the university community, aimed largely at acquainting university researchers with various industrial problems which require solution.

Although the larger industries have their own research facilities, the smaller ones are not always fortunate enough to be able to divert funds and resources for such purposes. For them, and even for larger ones that do not have basic research capabilities, the university is a largely untapped reservoir of ideas, technology, and in many cases techniques. Industrial inputs to this reservoir, in the form of questions, problems, and presentations, will naturally broaden the scope of university investigations, and thereby coordinate university efforts with those of industry.

At the receiving end, the Nation's industrial complex is a major beneficiary of the NASA University program. First, industry benefits significantly from the program's training features. Students participating in the program have no contract with the Government. Upon completion of their school work, they are not committed to go to work with NASA or any other Government agency. Many of them, probably most, actually do enter private industry; and their training in space-related fields can only enhance substantially the capabilities of the companies they join upon leaving school.

Second, industry naturally gains when it acquires new knowledge and technology, growing out of university research, when it has not borne the financial burden. In this connection, NASA is currently making a concerted effort to inform industry of new knowledge and technological innovations—not only resulting from university research, but also from its in-house and industrial contractor programs. Through its Technology Utilization Program, NASA emphasizes, for its own people as well as all its contractors, the need to identify specific innovations and to accelerate the flow of technical information from space research to nonspace applications. New developments—developments which cover such fields as electrical energy sources, materials, mechanics, and life sciences—are published and disseminated to industrial users as well as to scientific and technical trade journals and other appropriate media.

Pilot operations at certain regional centers are also helping potential users to obtain this technical information. The Midwest Research Institute has pioneered with NASA. It is certain industry will derive significant benefit from the space program in general and from the university program in particular.

It is clear then that the NASA University program is serving a critically necessary function within the Nation's overall space endeavor. It is providing necessary encouragement and assistance to dedicated young people who want to make as their career our reach to the stars. It represents a valuable adjunct to the research efforts being carried on in Government as well as industry. And it certainly encourages the university community to meet its responsibility to its students and the Nation by accepting its role in the challenge of space.

Within the context of these thoughts, it is safe to say that the give and take of the program—the two-way street—will serve to strengthen the Government, and the universities, and the industrial complex. As such, it represents further progress in the teamwork that has made this Nation the strongest and most prosperous in world history.

Session I—Training

Chairman: **Frank D. Hansing**
Chief, Training Division
Office of Grants and Research Contracts, NASA

Coordinator: **William H. Chapman**
Office of Grants and Research Contracts, NASA

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Space Training and Research at the University of Michigan

Ralph A. Sawyer

VICE PRESIDENT FOR RESEARCH AND
DEAN OF THE GRADUATE SCHOOL
UNIVERSITY OF MICHIGAN

THE IMPACT OF THE FINANCIAL SUPPORT OF NASA on the graduate training programs in space fields in a large university that has a strong graduate training and research program is the matter for discussion. In order to do this, I will outline the organization of the University of Michigan and its involvement in graduate training and research, particularly in the space-related fields.

The University of Michigan is a state institution. It is governed, however, by a board of regents elected by popular vote and responsible only to the people. Neither the governor nor the legislature controls the University of Michigan or dictates its admission, educational, or research policies. The elected regents have virtually the same freedom of action as is enjoyed by the trustees of a private university. The legislature is directed by the state constitution to give financial support to the University. To this extent, the legislature has an indirect control over the University, but on the occasions when it has attempted to use this indirect control to dictate educational policies or curriculum content, it has been rebuffed by decisions of the State Supreme Court and also by popular opinion.

Last fall the University had 29 103 resident-credit students, of whom 39 percent or 11 289 were advanced beyond the bachelors degree and enrolled in graduate and graduate-professional programs; 6920 of these students were enrolled in the Horace H. Rackham School of Graduate Studies, which administers all graduate work except a small number of purely professional programs. Of these 6920 students, 1924 were enrolled in physical science and engineering programs and another 671 in biological and health science programs with a possible involvement in space. Last year the Graduate School conferred 399 doctors degrees and 1910 masters degrees.

In 1964, the University celebrated the 50th anniversary of instruction in aeronautical engineering at The University of Michigan. The first course in aeronautical engineering was given in 1914 by Professor Felix Pawlowsky who came to The University of Michigan from France, where he had received his training in aeronautical engineering at the University of Paris in what was probably the first program of its kind in the world. In fifty years, the University has given 2731 degrees in aeronautical engineering, of which 847 were graduate degrees, and has graduated three of the current group of astronauts.

A large graduate program, of course, implies a large research program. NASA-supported research supervised by members of the faculty of the Department of Aeronautical and Astronautical Engineering at the present time has an annual expenditure rate of approximately $1.5 million a year. The total sponsored research program of the University (i.e., the research program supported by other funds than those received from the state appropriation and student fees and including support from Federal and industrial sources, endowment and gifts, foundation grants, and other outside support) amounted to $42 million in the last fiscal year. This research program of $42 million actually constituted 31 percent of the University's total operating budget of $136 million, of which $41 million came from the legislative appropriation. The percentage of federal research and development money as a fraction of the total budget is perhaps the smallest for any of the ten universities that together receive almost 40 percent of such money. This program at The University of Michigan has been increasing rapidly over the last 20 years and in the current fiscal year will probably amount to about $47 million. At the present time, the University has 23 active grants and 21 active contracts from NASA and the rate of expenditure under these grants and contracts is just under $4 million per year. To help house this NASA research, the University has built a Research Activities Building with its own funds at a cost of something over a third of a million dollars. NASA has provided a building grant of $1.7 million for a Space Research Building, which will be completed this spring.

It has always been the firm policy of The University of Michigan that its research program should be an integral part of its educational program. This means that research projects, with the exception of those vital to national defense and undertaken at the request of the Federal Government, are accepted only if they can become an integral part of the research program of the faculty of the teaching departments and if they can contribute to the training of graduate students. Last year, 1,878 graduate students were involved in and received some financial support from the sponsored research program, and about 100 graduate students participated in the research carried on under the NASA grants and contracts.

The research grants and contracts, while a vital part of the University's research and training program, of course, constitute only part of the support received from NASA. An extremely important part and one to be discussed in particular is the traineeship program established three years ago by NASA to provide direct support to graduate students. This NASA traineeship program, which now supports nearly 2 000 graduate students in areas related to the NASA technical program, is, of course, of vital importance both to NASA and the nation, because of the shortage of scientifically and technically trained research personnel and because of the large and increasing demands of the NASA space program for such personnel.

The urgent need for increasing the graduate training programs in this area was highlighted with great clarity by the recent report of the President's Scientific Advisory Committee, which, at President Kennedy's request, undertook in 1962 a study of the national resources of scientific and technical personnel in relation to the demands placed on these resources by requirements of space exploration, military security, economic progress, medical advancement, assistance to underdeveloped nations, and staffing of higher education. In a report published on December 12, 1962 the committee found that there was a need for a large increase in scientific and technical manpower. It pointed out "that from 1930 to 1960, while the total civilian labor force increased 40 percent, 'professional, technical and kindred workers' increased 125 percent, engineers 300 percent and scientists 600 percent." These figures indicated a change in the character of the work force in this country, which is evidenced by such things as the great decrease in needs for agricultural manpower, the growing industrialization of the country, and the greater complexity of the industrial, space, and military technology. It was the conclusion of the committee that the output of doctorates in engineering, mathematics, and physics was not increasing rapidly enough and that the rate of production should be substantially stepped up so that the output of doctorates in these fields should be increased by 150 percent in the decade 1960 to 1970 in comparison with a 50 percent increase in the decade 1950 to 1960.

The basic problem in increasing the rate of training of doctoral candidates in scientific and engineering fields is financial. A graduate student in this country customarily requires financial support; his parents usually have supported him through his undergraduate program; but as he enters the graduate program, he has become of age, he is often married, and it is traditional for the graduate student to look after his own financial needs and to support himself either by teaching, research assisting, or fellowships. While teaching assistantships and research assistantships are both valuable parts of the training of a graduate student, if his training is to be expedited, it is best done through the use of traineeship or fellowship support. The effect of such stipends in expediting the programs of graduate students will be discussed later.

The University of Michigan received 10 NASA traineeships in the first program for the academic year 1962–63, 15 in the 1963–64 program, and 15 in the 1964–65 program. At The University of Michigan at present, there is one of the largest groups of NASA trainees, and perhaps one of the most broadly representative of the whole space field. Because of the size and breadth of our graduate program encompassing as it does engineering, physical sciences, biological, and medical sciences, and the field of human behavior, it is possible to consider for inclusion in this traineeship program almost all the areas of learning of interest to NASA. The current trainees encompass 14 different fields of study, including, for example, astronomy, psychology, geology, physics, chemistry, mathematics, aeronautical and astronautical engineering, information and control engineering, mechanical engineering, electrical engineering, and communication sciences, among others.

Of particular interest among these fields of studies are two interdepartmental fields, communication sciences and information and control engineering. Communication sciences are interdisciplinary in nature and involve five bordering disciplines—mathematics, electrical engineering, physiology, psychology, and linguistics—or in other words, five departments in three colleges of the University. The program is concerned with understanding, on a theoretical basis, the communication and the processing of information by both natural and artificial systems. Among other things it is concerned with the use of computers for investigating languages and symbolic processes and also with the development and use of languages to study the nature of computers, as well as with procedures for information processing by man, by machine, and by systems involving both man and machine. This is a new, broad program of great importance to space-age work.

Information and control engineering is likewise an interdepartmental program involving physics, mathematics, aeronautical and astronautical engineering, electrical engineering, and chemical and metallurgical engineering. The program is intended to cover the dynamical aspects of systems engineering including measurement, information theory, data transmission, computers, feedback control, and random processes and their relation to systems of all kinds. Again, this is a program of great importance in modern defense and space development.

The Executive Board of the Graduate School has considered at some length the factors that are to be considered in awarding NASA traineeships to obtain only highly qualified students who are definitely candidates for the doctoral degree and who are interested in a "space science" area. Consequently, in addition to specifying these selection factors, the executive board has prepared a statement to indicate the general scope of "space-related" specialties as an aid to the University departments in recommending such scholars and to provide a basis of discrimination for the NASA trainee selection committee of the graduate board. The criteria given in this statement are as follows:

Any studies of regions from the ionosphere on outward, whether theoretical, experimental from earth-based equipment, or experimental from satellites or rockets, can be considered space work. Also included would be the development and design of equipment intended for such studies, as well as fundamental research that may result in improved space techniques and/or equipment. In terms of space work a "space-related" specialty is one that involves a significant proportion of its professionals in space work.

Thus, mechanical engineering could be considered space-related, but automotive engineering would not automatically be; similarly, electrical engineering is admissible, but power generation and distribution engineering are not automatically. Although automotive engineers might well work on a lunar exploration vehicle, the vast majority of automotive engineers are otherwise engaged, so that automotive engineering is not immediately space-related.

Basic research pertinent to space activities can be envisioned in astronomy, biochemistry, chemistry, communications science, geology, mathematics, medicine, physics, psychology, and other areas as well as in the various areas of engineering.

The NASA trainees, as is to be expected, are among the best graduate students in their field, and all are proceeding rapidly toward the accomplishment of the doctoral degree. One has already completed his doctoral work, five more will probably receive their doctoral degrees this spring, and virtually all of the others, except some of those first appointed for the current year, are already at the research level in their doctoral program.

A most significant feature of the NASA traineeships is that students may hold these appointments for three years if their work and progress are satisfactory. They are, in fact, almost the only available grants that guarantee a tenure of three years. In order to investigate the importance of such appointments, the graduate school carried out a study on the relation between employment and/or scholarship awards and the duration of doctoral programs. This study, which was preliminary, covered 205 individuals who received the doctoral degree in February 1961. Almost all of these students had held either research or teaching appointments or fellowships during their period of study. As might be expected, those who had to teach or assist in research during their programs took a somewhat longer time than the average to complete the program. Those who had a fellowship for one year only showed little deviation from the average. Students who held fellowships for two years or more, however, completed their graduate program about half a year faster than the average student. In other words, there is a clear indication here that the plan adopted by NASA in the award of their fellowships to support the student for as much as three years makes a real contribution to shortening the duration of the doctoral program. Since shortening the duration of the program is the most practical way to expedite the rate of production of doctorates, this program has made a significant, important, and unique contribution to graduate training in science.

Lindsey R. Harmon has made a somewhat analogous study for the Office of Scientific Personnel of the National Academy of Sciences—National Research Council on the effect of fellowships on the acceleration of doctorate attainment. His study indicated that fellowship holders on the average completed their doctorates slightly over a year earlier than those not awarded a fellowship. His study, however, was not able to evaluate any difference in quality between fellows and nonfellows or the difference between those who taught or worked and those who held fellowships, or the difference between those who held a fellowship for one year or more than one year. Nevertheless, his study also indicated the importance of fellowships in accelerating the rate of production of doctorates.

Another important factor in the NASA traineeship program is the provision of training expense allowances to accompany the fellowships. The Executive Board of the Graduate School has considered the best use of these funds. The simplest solution would be to give to each department the allowance that accompanied the fellowships awarded to that department. However, the executive board has chosen to handle this money as a research fund available to any of the departments that have received fellowships, but to make awards of somewhat larger block amounts to satisfy important needs of particular departments. Thus, it has awarded $6000 to the Department of Aeronautical and Astronautical Engineering for library acquisitions to strengthen the library holdings in this area. It has given $10 900 to the Department of Mechanical Engineering for important research equipment for the use of research programs related to the space research activities of the Department, and it has given $7500 to the Department of Nuclear Engineering to enable it to obtain a laser and an oscilloscope for its important research in the fields of laser technology. Smaller amounts have been given to three other departments.

While this use of the expense funds understandably does not satisfy the departments who did not receive any, in general these departments have other sources of funds at their disposal and it seems to the executive board desirable to make use of these NASA institutional funds in amounts that will significantly strengthen the space-oriented work of the department concerned.

The question has sometimes been raised whether the large amounts of fellowship assistance made available in scientific fields by NASA as well as by the National Science Foundation, the Atomic Energy Commission, and the Public Health Service, have not significantly altered the distribution of students among the various areas of graduate work and, in particular, whether they have not weakened the graduate work in the arts, humanities, and social sciences. Our studies indicate that this has not been the case at The University of Michigan. Actually, in the period 1947 to 1950, 37 percent of the graduate enrollment was in science and engineering and it must be remembered that this was in the immediate postwar period when there was an increased interest in science almost everywhere. For the period 1959 to 1962, however, enrollment in the sciences and engineering was 35 percent. In other words, the fraction of our students in science and engineering areas in the graduate school has actually decreased slightly. I do not know if this is a national trend because, of course, at The University of Michigan the humanities and social science programs have been strengthened markedly during this period. In spite of the relative decrease in enrollments, however, it appears that the influence of the NASA fellowship and traineeship programs has been far reaching.

The availability of traineeship awards may encourage students who would otherwise not think of graduate study because of its cost, to plan for a career in science or engineering, subject only to satisfying academic standards, and without regard to personal financial standing. Once embarked on graduate study, fellowships and traineeships enable the student to devote his full energy to the increasingly exacting and complex studies required for advanced degrees in science and engineering. The student thus can complete his graduate program in a shorter time than otherwise and so become available in the shortest practical time for professional work in industry, government laboratories, or on a university faculty.

What is hoped and expected is that potential scientists and engineers, otherwise financially handicapped, will be encouraged at an early stage in their academic lives to consider graduate study in the sciences and engineering, if they have both the intellectual qualities and active interest to pursue the intensive and demanding course of study that such fields require as a preparation for professional life.

In conclusion, the NASA traineeship program, then, has made a marked contribution to graduate training in the areas of interest to NASA. First, the provision of three-year grants has made a definite contribution to the struggle to increase the rate of production of doctors in these areas by shortening the length of the program. In a program the size of the NASA one, this can mean that, in space science fields, 1000 students each year may have their doctoral programs accelerated by from six months to a year—a vital contribution to our needs for specialized personnel. Second, the expense funds that accompany the traineeships, in addition to paying the actual cost of education, provide funds to be used at the discretion of the university to strengthen space age research, are of tremendous importance. Most universities today have all too few free funds of this nature and at the University of Michigan extremely good use can be made of them. The NASA traineeship program, then, although not our largest student aid program, has been a most useful and important one in opening graduate possibilities to a highly qualified group of students and in accelerating training for these students in the space age areas.

NASA's Frontier Not in Space

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PRESIDENT, KENT STATE UNIVERSITY

To a real degree, I am here as a representative of "a university just beginning to develop graduate curriculums in the space-related areas." As I scan the list of institutions involved in the NASA training programs, I seem to spot no more than 12 universities whose doctoral programs in these space-related fields have begun within very recent years.

After several years of internal study, in 1958 Kent State University asked our regional accrediting association, the North Central Association, to take jurisdiction of our hoped-for venture into doctoral programs of study. In what was then a novel arrangement, the Association suggested Dr. Ira Baldwin as a general consultant to supervise both the university and the special field consultants who were engaged in each projected new program. Hence, the University officials took no single step until we felt that our colleagues and the accreditors would approve. We announced our programs in chemistry, including chemical physics, and in certain fields of the biological sciences, including physiology, in the fall of 1961. We simultaneously launched programs in three nonscience fields. Since it is germane to later remarks, it might be noted that in all our doctoral programs there are controls on the number of students to help assure early establishment of a quality tradition.

At present we have five NASA trainees, two in their second year and three in their first. A year from now we will have nine. Thus it may be a bit too early to ask for definitive comments on student and faculty outcomes. Nevertheless, a few clear facts are now apparent. These observations, in addition to my own, include those from some of the faculty. Further, some of these points were reviewed with officers in other "newer" institutions.

If, as I surmise, these newer programs are represented by about one-tenth of all the institutions holding NASA training grants and if it is assumed that the number of traineeships per institution is no more than half that of the more established programs, then it appears that I am speaking with respect to less than 5 percent of all NASA trainees.

Whatever the degree of numerical significance, I submit that the program is an unalloyed contribution to excellence, peculiarly so for this group of universities; and its relative effect is incomparably greater at Kent State University than for other schools. Because of our relatively brief experience, some of the specific points of interest cannot be exactly or finally described. There has been some encouragement to interdisciplinary study. Beyond any doubt, these interests will grow. Although we had a chemical-physics program before the NASA grants, the grants have further encouraged this aspect. Two of our five trainees are in that area. There is also evidence of closer research contact between biology and chemistry. New programs are developing in biophysics and biochemistry.

It is not yet possible to point to the acquisition of much highly specialized equipment but that will surely come to pass. The NASA program support money for 1965 is about 10 percent of the amount of University money (excluding extramural funds and contingency money) budgeted for equipment and supplies to these two science departments. An extra 10 percent is tremendously important. Further, and possibly paradoxically, we have diverted University funds and private moneys into equipment important to one of these NASA traineeships.

The students are doing very well indeed. Grades are fine, general program progress is good, and at this point there appear to be outstanding prospects. The time required for the doctorate will be clearly foreshortened. For example, one student is studying physiological changes associated with maturation of mammalian blood cells. This study can have a relation to the effects of environmental conditions of potential interest to NASA.

The program has been a superb contribution to recruiting good students. First, the stipend is relatively good, covers 12 months, and involves a factor for dependents. Particularly important to a newer graduate program is the "cachet" or endorsement implied by the assignment of a NASA grant. Despite our doctoral accreditation by the North Central Association, this endorsement means much in securing good students under present competition with older and well-established institutions. It has an effect going beyond possible candidates for the training grants and spills over into other fields of study. The number of faculty members has increased. The greatest faculty effect, though, is found in morale and in the ability to use some new research support funds.

Our faculty and academic officers have only friendly comments for the program and its organization. The fact that we hold the research contract with the Plumbrook Reactor of NASA is an added potential for the trainees. In net, the training program as we see it is a clearcut strengthening of the basic and applied space-related sciences and is administered in a way to encourage further growth.

NASA has held that space activity is an extension of the sciences, not a unique science in itself. Granted that interdisciplinary activities inevitably do and should result, the goal of broad space-related science is reflected in the broad interpretation of space-related science by NASA.

There is apportunity for scientists to pursue their ideas. The University holds wide autonomy in placing the students and in focusing the supports from the program. Just as we have gone from Explorer up through Mariner and beyond, so too will the philosophy of NASA university training grants help to produce ever more imaginative and creative sciences.

These are the reasons, then, why I say that the NASA training grant program is an unalloyed contribution to excellence for the "newer" graduate study programs. We become participants with NASA and with other universities in meeting a challenge which is national and which is more than science alone.

Predoctoral Training Grants at a Private University

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DEAN OF ENGINEERING
RICE UNIVERSITY

BEFORE DISCUSSING NASA'S PREDOCTORAL TRAINING PROGRAM at a private university it would be appropriate to say a few words about the particular private institution which provides the basis for this discussion. Rice University is a relatively small coeducational institution located in Houston, Texas, with an undergraduate enrollment of about 1750 students and a graduate enrollment of approximately 600. It does not maintain any professional schools such as law, medical, divinity, or business schools. Since there are no evening or summer courses, virtually all 600 graduate students are in full-time residence. In its relatively short history of about 52 years, Rice University has been fortunate to attract a student body of exceptionally high academic standing. As a result, Rice University ranks now 11th among the schools in the nation as the choice of National Merit Scholars and in third place when this criterion is related to the size of the incoming freshman class. Similarly, College Board averages and other standards clearly reveal the exceptional quality of the undergraduate body. As far as Rice's educational policy is concerned, it tries to contribute to society graduates able to think and question, educated to comprehend and to cope with the rapidly changing world. The emphasis is manifestly on breadth of education for students in all disciplines. Being a nondenominational school whose students until now have not paid tuition, Rice University has evolved into a unique educational institution in the southwest of the United States, whose level of excellence clearly transcends a regional frame of reference.

Although the undergraduate enrollment has been kept virtually constant over the last years, the University has a rapidly growing graduate school. In this school a special effort is made to strike a happy balance between research on one hand and instruction on the other hand. In this connection it has been clearly recognized that a basic research program is a most important element of graduate education, and such a program can be sustained only by individual, scholarly dedication of all the members of the faculty. It has been the policy of the University to assure that the choice and control of the research projects rests exclusively with the investigators.

In short, Rice University is an institution which because of its size and its background possesses a great deal of administrative and academic flexibility and which is determined to attain the highest level of academic excellence in all the areas of its endeavor.

THE DEVELOPMENT OF THE GRADUATE PROGRAM AT RICE

The great future needs of this country for personnel trained in the sciences and engineering have received much publicity. The Bureau of Labor Statistics predicts a rise in the number of scientists and engineers from about 1.1 million in 1959 to about 2 million in 1970, corresponding to a growth rate approximately four times that projected for the national labor force as a whole. (See ref. 1.) It is indeed gratifying to note that the production of Ph. D.'s in the physical sciences and engineering has increased substantially in the last 10 years. As an example, the number of engineering doctorates granted has increased threefold since 1950 (see ref. 2) ; yet, the geographical distribution of the production of scientific talent is still very uneven.

In this connection it would be well to mention here the special conditions that have prevailed in the southwest of the United States with respect to graduate education in the sciences and engineering. Approximately one-third of all Ph. D. degrees given in 1962 were awarded by universities in the New England and Middle Atlantic States. Although the relative academic importance of these regions was even greater in 1920, when approximately one-half of all Ph. D.'s given were granted there, the southwest of the United States still lags far behind the East Coast, the West Coast, and the Midwest, as far as graduate education is concerned. The consequences of the unevenness of the geographical distribution of graduate education are illustrated by the following statistics (ref. 3) : Although 5 percent of the people holding Ph. D.'s in physics were born in the southwest of the United States, only 3.3 percent work there, a net drain of about 30 percent!

It is with these general conditions in mind that Rice University has made special efforts to increase its graduate enrollment steadily without affecting the high quality of its program. Although only a few years ago, in 1960, the total graduate enrollment was approximately 350, it is now slightly above 600. It is estimated that the full-time graduate enrollment for 1970 will be greater than 850.

Clearly, the building of a graduate school of good quality is costly. The increase in faculty, facilities, equipment, and expenses has to be budgeted, and it is evident that the funds for the enlargement of a graduate school cannot come from tuition, endowment increase, or research contracts alone. In past years, Rice University has not charged significant amounts of regular faculty salaries to research grants or contracts. This, in a sense, is the University's contribution to its fundamental research program in recognition of its obligation not only to transmit but also to create knowledge. At the present time more than half of all graduate stipends come directly from University funds, another substantial contribution of the University to the graduate program. Yet, funds made available for these purposes cannot rise at the same rate as the graduate school must grow in order to satisfy national and, in particular, regional needs. Means had to be found to provide funds for the tuition and stipends of graduate students attending Rice University. In this respect the NASA Predoctoral Training Program instituted in 1962 has been an invaluable asset to the growth of the graduate school at Rice University.

THE NASA PREDOCTORAL TRAINING PROGRAM AT RICE

The NASA Predoctoral Training Program at Rice began in September 1962 with the award of 10 NASA traineeships for the period of 3 years. Through supplementary grants the University received 10 additional NASA traineeships beginning in September 1963 and 15 NASA traineeships beginning in September 1964. Recently the University was awarded a supplementary grant for an additional 15 NASA traineeships, which more than replace the 10 original traineeships which will be terminated in September 1965 after a period of 3 years. Thus, there will be a total of 40 NASA traineeships at Rice University starting in September 1965.

It is often difficult for a private institution to plan ahead over a long period of time. The sustaining nature of the NASA Predoctoral Training Program is therefore a particularly desirable feature. Needless to say, the funding of traineeships on a 3-year basis, rather than a year-to-year basis, adds to the stability of the program and reduces administrative work substantially.

The program is administered by the Graduate Council of the University, which decided from the outset that a NASA traineeship should be a particularly prestigious fellowship. This meant that the Council would select the students purely on the basis of scholarship and past academic performance. Selection is made among those candidates whose names are submitted by the various science and engineering departments. The departments are encouraged to submit

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complete records of their best graduate students, and these records are judged individually by each of the six members of the Graduate Council. In order to maintain the highest standards associated with this traineeship, the Graduate Council may discontinue a traineeship in the unlikely event that the academic performance of a trainee deteriorates. Records of all NASA fellows are reviewed annually by the Graduate Council. As a result of these measures the title "NASA fellow" carries with it special academic distinction on the Rice campus.

From the funds provided by the grant, the University retains $1500 per trainee each year as unrestricted income in lieu of tuition. This amount corresponds to the cost of graduate tuition which was introduced this year. An additional amount of $1500 per NASA fellow is transferred to departmental budgets in order to help the departments defray the expenses of research carried out by NASA fellows. The latter adds considerably to the motivation of the departments to submit their very best students as candidates for NASA fellows. As far as the stipends paid to the students are concerned, primary consideration is given to the students' needs in terms of family obligations and personal circumstances, but academic performance also plays an important part. The University has an understandable interest in completing the graduate education of every student in the shortest possible time. Every effort is made, therefore, to keep students working full time on their thesis research during the summer months while in residence at the University.

In order to keep the turnover of NASA fellowships at a minimum, the fellowships are generally awarded to students likely to finish their doctoral programs within the prescribed period of 3 years. In most cases this means that the student has been at the University as a graduate student for at least 1 year. This, in turn, facilitates greatly the evaluation of the student's record and his selection as a NASA fellow. Incidentally, the failure to recognize clearly these conditions at the beginning of the first grant led to a greater than desirable turnover of students. This condition, since then, has been rectified. It is inevitable, however, that some students either leave the University before concluding their graduate work, or conclude their graduate work before the allotted time of 3 years has expired, or, in some cases, prefer to accept a fellowship granted by another source, such as the National Science Foundation. In these cases, NASA fellowships valid for 1 or 2 years are freed and are distributed to suitable candidates by the Graduate Council with the clear understanding that these fellowships have only limited duration.

Of the 35 NASA traineeships presently in force at Rice University, 3 are in the field of mathematics, 11 in the field of physics, 4 in chemistry, 2 in geology, 9 in engineering, and 6 in space science. Of the 13 students who gave up their NASA fellowships prior to the termination of the 3-year period, 2 received their Ph. D. degrees at Rice, 3, after receiving their master's degrees, transferred to other universities, 1 requested a leave of absence, and 4 accepted other fellowships at Rice University. Only 2 discontinued their graduate studies, and only 1 was dropped by the Graduate Council in view of inadequate performance. As the first of the 3-year grants comes to a close this summer, 8 graduate students holding NASA traineeships are expected to receive their Ph. D. degrees.

What has been the effect of the NASA traineeship program on Rice University? Above all, the program has made possible a more rapid growth of the graduate enrollment and subsequent production of graduate degrees. The number of NASA fellows represents an addition to the graduate enrollment at Rice University. The number of graduate students whose fellowships are carried on the regular budget of the University has not been affected by this grant. Indeed, with an increased graduate enrollment of about 100 every year during the past few years, the University's contribution to assistantships and fellowships has grown substantially. NASA traineeships can therefore not be interpreted as having caused any curtailment of the contribution of Rice University to its own graduate program in space-related sciences and engineering. With the increasing number of graduate students in science and engineering, partly due to the introduction of NASA traineeship funds, more extensive instructional and research programs in these areas were generated. Furthermore, the relatively generous stipend associated with the NASA traineeship tends to attract outstanding students to the campus from a broad geographical background or keeps them on the campus, since they are able to continue their studies without having to resort to remunerative work on the outside. It is believed that the prestige associated with the NASA fellowship on the Rice campus represents an additional force to keep the students at Rice and, as a consequence, in the southwest of the United States. Since the inception of this program, several interdepartmental programs have been created at Rice. It is difficult to say whether or not these programs would have been created without the presence of NASA traineeship funds; yet, the possibility for a given department to obtain fellowships not provided for in its particular budget, no doubt, facilitates the creation of interdisciplinary programs. In the last few years such interdisciplinary programs in the fields of computer science, in which the Departments of Philosophy, Mathematics, and Electrical Engineering are participating; systems science and engineering, in which the Departments of Electrical and Chemical Engineering are participating, and materials science, in which the Departments of Mechanical Engineering, Electrical Engineering, and Chemistry are participating, have been established. Such interdepartmental activities, which can be carried out with relative ease within the flexible structure of a private university, represent a very desirable and important trend in the field of graduate education. It is expected that more programs of this nature will be created.

CONCLUDING REMARKS

There is no doubt that the NASA traineeship program is a very important ingredient in the development of a greater number of first-class universities in America. But, as Henry Heald, President of the Ford Foundation, has pointed out, it is difficult today for a university to realize aspirations of greatness. The pressures are great, the costs high, and the competition keen. Yet, the need for outstanding scholars is also growing rapidly. It is most fortunate that the National Aeronautics and Space Administration has had the foresight of providing universities with this program.

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NASA Summer Institutes

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THE DEVELOPMENTS IN SPACE SCIENCE AND TECHNOLOGY pose a variety of problems in undergraduate education. This paper concerns a small experimental program in undergraduate education sponsored by NASA.

During the past three summers NASA has supported an Institute in Space Physics at Columbia University. A similar program has developed at the University of California, Los Angeles. During the summer of 1963, UCLA was host to a Summer Program in Planetary Physics. In the summer of 1964, UCLA and the California Institute of Technology jointly participated in a similar program. Also in 1964, the California Institute of Technology and the Jet Propulsion Laboratory developed a summer course in space technology. A principal goal of all the summer institutes was to acquaint upper division undergraduates, and in a few instances first year graduate students, with the substantive problems of space science and space engineering. While the prime purpose of the three Institutes was roughly similar, the techniques employed to achieve the goal differed among the three Institutes. The various programs suggest a variety of approaches to the problems of education posed by the new developments in space.

Planetary physics encompasses many problems not ordinarily taken up in the usual undergraduate curricula. Since the problems demand a high level of attainment in physics and mathematics, it may be unwise to dilute the undergraduate program with special, topical courses covering planetary and space physics. At many smaller colleges and universities, there is the additional problem that the faculty does not include individuals active in research in the new subjects. An alternative to the development of special undergraduate courses at many institutions is to use the time available to the students during the summer recess. During this time special programs can introduce students to problems of space and planetary physics without interrupting or delaying their basic undergraduate education. The time at which the student is introduced to the problems of planetary physics is most important. The student should have a sufficient background in physics and in the basic sciences to appreciate the problems of planetary physics. Yet he should not be sufficiently advanced in his education to become committed to a particular field of science with the result of only a peripheral interest in planetary physics.

In discussing the Summer Institutes, I will concentrate on the experiences of UCLA–CIT. At the same time, in developing this description, I will comment on how the Columbia program and the CIT–JPL program differed from the UCLA–CIT program.

Last summer the planetary physics program at UCLA–CIT covered 10 weeks. Seven weeks of this period were devoted to a series of lectures and 3 weeks were devoted to individual research by the participating students. The Columbia and JPL–CIT programs were of 6-week durations.

The first 5 weeks of the UCLA–CIT program were devoted to a lecture series on four selected problems. The aim was to introduce the undergraduate to specific problems in space physics; the lectures would take him far enough along in these problems so that he would become aware of current excitement and interest, and perhaps arrive at a point where he could begin to conduct his own research in a specific area. The four problems developed at UCLA were:

(1) The determination of the gravitational field of a planet by observing an artificial satellite. This question leads to the consideration of the interiors of planetary bodies, their thermal histories, and chemical evolution.

(2) The escape of an atmosphere from a planet. This limited question is closely connected with the problems of the constitution of the atmosphere and the development and origin of planetary atmospheres.

(3) The lifetime of particles trapped by the Earth's magnetic field. This restricted problem introduces such questions as the origin of the particles in the radiation belts and the interaction with the atmosphere.

(4) The nature of the solar wind. The solar wind interacts with the magnetic fields of the planets giving rise to a variety of interesting questions.

Seventy-five hours of lectures were required to introduce the above problems in a substantive way. These morning lectures were supplemented by a similar number of hours of afternoon meetings. The afternoon sessions were partly devoted to additional lectures by University of California faculty and partly to the solution of set problems.

A 2-week lecture series at CIT followed the 5-week program of lectures at UCLA. These 2 weeks were devoted primarily to introducing the students to the observational methods of planetary and space physics and was under the direction of Bruce Murray. The lectures and laboratory were supplemented by field trips to the CIT radio telescope at Owens Valley, to the planetary telescope at White Mountain, and to Mount Wilson.

The final 3 weeks of the Summer Institute were devoted to student research projects. I can best indicate the nature of these programs by illustration. One student, from Capital University, concerned himself with the size distribution of lunar craters. He worked out a theoretical size frequency distribution on the basis of rather specific assumptions regarding the influx of meteors and the nature of the lunar surface, and then he compared his theoretical conclusions with the frequency distribution derived from an analysis of the Ranger VII photographs. He determined that for craters above a certain size, something on the order of a couple hundred meters in diameter, the theoretical and observed distributions were quite similar. Below 200 meters, he observed, frequencies fell significantly below the predicted frequencies; this is attributed to the reworking of the meteor craters by secondary particles generated by the primary meteor impacts.

A second example is drawn from a study by an MIT undergraduate, who was concerned with the infrared brightness temperature of the planet Mercury. New observations carried out at White Mountain have determined brightness or the temperature of Mercury in the infrared as a function of the phase angle. The student showed that if Mercury indeed had an atmosphere, the temperature distribution would have a different phase dependence than it would if there were no atmosphere. He then compared the observations with his theory and demonstrated that the present observations limit the extent of the atmosphere on Mercury to a rather low value and indicated how further observations could reduce this limit still more.

As a third example, a student from Vassar developed data taken by the radioastronomical group at Owens Valley on a spiral nebula. She was able to determine in a fairly unique fashion the total mass in the galaxy and the distribution of the mass between the stars and the hydrogen gas.

This program at UCLA differed from that conducted at Columbia in several respects. The Columbia program is under the direction of Robert Jastrow. He has emphasized a general overview of space physics. A 5-week series of lectures is followed by 1 week in which the students tour selected research facilities of NASA. The past summer the students visited Goddard Space Flight Center, Marshall Space Flight Center, and Cape Kennedy.

The program in space technology conducted at California Institute of Technology and the Jet Propulsion Laboratory was directed by E. Sechler. This program combined a general course of lectures on space environment with specific lectures by staff members on definite topics within the areas of space technology.

In evaluating our programs both Dr. Jastrow and I feel that we have interested a number of able undergraduates in the problems of space physics. We believe a substantial proportion of the more than 200 students who have participated in the summer institute program will continue to doctoratal degrees in space-related sciences. From the 32 students who attended the UCLA 1963 program, 28 are now involved in graduate education in geophysics, space physics, or astrophysics.

The students' reactions to the program have been uniformly favorable. They value most the lecture material and the participation in individual research projects.

During the summer of 1965, there will be a continuation of the engineering program. This year it will be sponsored jointly by UCLA and the Jet Propulsion Laboratory. The Columbia-UCLA programs have been combined to a single program with Dr. Jastrow and myself as codirectors and will be held at Columbia.

I suspect that the programs described above could be very usefully expanded, particularly since in our own developments we have tended to take only exceptionally well prepared students. This has excluded a large number of very able students, particularly from the smaller colleges, who have not had sufficient background in mathematics and physics to take part in this accelerated summer program.

In summary, then, I would say that the Summer Institutes have provided a very exciting and interesting experiment. We hope to continue various experimental approaches to this kind of education. I believe, as do the other people who have been involved in the program, that it is, indeed, a valuable contribution to the general problem of interesting our ablest students in the problems of geophysics, astrophysics, and space physics.

ASEE-NASA Summer Faculty Institutes

Max Anliker

ASSOCIATE HEAD, DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS
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IT IS QUITE CLEAR that the extent of the contribution of the university community toward the national efforts in aeronautics and space exploration depends largely on the degree to which engineering and science professors keep up with the rapid developments in NASA centers and aerospace industries. For a maximum effectiveness of the pertinent graduate teaching and research, it appears desirable to give interested faculty members an opportunity to become directly involved in the research in progress at the various NASA laboratories.

Recognizing these facts, the American Society for Engineering Education (ASEE) created the Space Engineering Committee, whose task is to suggest and organize special programs that would lead to a closer interaction between the educational centers and NASA. With Dr. Phil Powers of Purdue University as Chairman, this Committee proposed as a first program a series of summer institutes, each to be jointly directed by one or more universities and a neighboring NASA center, for example, by Case Institute of Technology and the Lewis Research Center in Cleveland, Ohio.

The purpose of these summer institutes is to provide an opportunity for engineering and science educators to engage actively in research in a NASA laboratory for a period of 10 weeks and at the same time to attend advanced courses and seminars related to the research. It is hoped that such a prolonged association of university professors and NASA engineers and scientists will result in mutual stimulation and help the faculty to enliven the programs offered to students with an interest in the aerospace field. While the NASA centers are expected to select suitable research topics and assign a research advisor to each of the participating faculty members, the codirecting universities are responsible for organizing and teaching the special courses and seminars, as well as for the general administration of the institutes.

In the interest of long-range objectives, the ASEE and NASA decided that the participants, designated as Faculty Fellows, should predominantly be young engineering and science teachers, preferably from colleges and universities with a small graduate study program in space-oriented fields and limited research opportunities in areas of major importance to NASA. They should have a minimum of 2 years of teaching experience at the college level and must be U.S. citizens. Moreover, each Faculty Fellow is expected to have a scholastic background equivalent to a Ph. D. degree and give evidence for a minimum basic competence necessary to contribute to the research at the respective NASA laboratory. In addition, his institution should furnish a statement setting forth the particular and general benefits to be realized by the school as a result of the candidate's participation. Each Fellow is to be offered a stipend commensurate with his academic salary and also a travel allowance. To strengthen his potential for future research, he may be invited to return during a second summer for follow-up work and study.

The financial support of the summer institutes is to be provided by NASA through contracts with the codirecting universities.

The practicability of the ideas and plans as formulated by ASEE Committee on Space Engineering was assured to a large extent by the work of Walter T. Olson from the Lewis Research Center and Isaac Greber from Case Institute of Technology, who developed the basic format of the summer institutes. Also, the idea of such institutes was wholeheartedly endorsed by the research staffs of the NASA Centers.

During the summer of 1964 a pilot program of three ASEE–NASA summer institutes was conducted. The universities and corresponding NASA centers involved are listed in table I, together with the respective codirectors.

Each of these institutes had its characteristic features which reflected particular strengths of the participating center. The research areas and special courses that were made available to the Faculty Fellows are summarized in table II.

The location of the universities associated with the Langley-VARC Institute (Virginia Associated Research Center of the University of Virginia, Virginia Polytechnic Institute, and the College of William and Mary) required the special courses to be held at the center itself. Half of the lectures organized for the Case-Lewis program were presented at the Lewis Research Center and half at the Case Institute of Technology. The close proximity of Stanford University and the Ames Research Center permitted all the courses and seminars to be held on the university campus. They were offered as part of the regular summer session, and a few of the advanced Ph. D. students were

Table I.—1964 ASEE-NASA Summer Institutes

Universities	NASA centers
Case Institute of Technology Cleveland, Ohio *Codirector:* Isaac Greber Associate Professor of Aeronautical Engineering Case Institute of Technology	Lewis Research Center Cleveland, Ohio *Codirector:* Walter T. Olson Assistant Director Lewis Research Center
University of Virginia Virginia Polytechnic Institute College of William and Mary *Codirector:* Edward C. Stevenson Professor of Electrical Engineering University of Virginia Charlottesville, Virginia	Langley Research Center Langley Field, Virginia *Codirector:* John E. Duberg Assistant Director Langley Research Center
Stanford University Stanford, California *Codirector:* Max Anliker Associate Professor of Aeronautics and Astronautics Stanford University	Ames Research Center Moffett Field, California *Codirector:* John Leveen Chief, Employee Development Branch Ames Research Center

also given the opportunity to attend. In spite of the limited publicity given to these institutes approximately 200 faculty members responded to the announcement.

The 42 Faculty Fellows taking part were chosen in accordance with the objectives of the program. For each institute the selection was made jointly by the two codirectors and the research supervisors.

Although no geographic considerations were applied, no university was to be represented by more than three faculty members in any of the institutes. Table III enumerates the participants according to the location of their academic institutions. Dividing the states into groups from east to west, we had 21 Fellows from Eastern states, 16 from the Midwest and 5 from the Far West. A North-South division of the states separates the Fellows into 20 from the North and 22 from the South (including Arizona).

At the end of the 10-week period each participant submitted a research report in the form of a working paper or summary. In the case of the Langley-VARC institute they also gave oral presentations on their research accomplishments to the entire group of Faculty Fellows and research supervisors.

To permit an overall critique of the pilot program each Fellow and his research advisor were asked to complete separately evaluation questionnaires and to make recommendations for improvements of the

Table II.—Summary of Research and Course Programs of 1964 ASEE-NASA Summer Institutes

Institutes and number of participants	Research areas at center	Courses offered by codirecting universities
Case-Lewis (13 Fellows)	Combustion Heat Transfer Lubrication MHD Power Generation Micro Power Logic Circuitry Nuclear Reactor Engineering Materials and Metallurgy	Sequence of lectures (60 hours total) on selected topics in Chemical Rocket Technology with special emphasis on: Combustion Heat Transfer Chemical Kinetics Chemical Thermodynamics. Transport Properties Propellant Behavior
VARC-Langley (15 Fellows)	Structural Dynamics Materials Physics Aerophysics Instrumentation	Lecture series comprising 5 topics: Structural Dynamics Materials & the Space Environment Fluid Mechanics and Aerodynamics. Plasma Physics Communication in Space
Stanford-Ames (14 Fellows)	Space Physics and Plasma Dynamics Thermodynamics and Gasdynamics Guidance and Control Environmental Biology Physiology Biotechnology	Space Technology Seminar on topics related to research areas (9 sessions) and 4 special courses (30 lecture hours each): Spectroscopic Methods in Gasdynamics Advanced Hypersonics Modern Control Theory Dynamics of Viscous and Non-Newtonian Fluids—Hemology

institutes. The data collected were then reviewed in detail at a meeting of the Space Engineering Committee, which was also attended by all codirectors and by representatives from NASA Headquarters. The comments of the Faculty Fellows, the research supervisors and codirectors on the merits of the program were uniformly enthusiastic. As to the suggestions for improvement, they dealt mainly with minor administrative details such as scheduling of classes and early announcement of the institutes.

Table III.—1964 ASEE–NASA Summer Institute Participants Enumerated by Location of Academic Institution

Ohio	5	Massachusetts	1
Virginia	4	New Hampshire	1
New York	4	New Jersey	1
Pennsylvania	3	South Carolina	1
North Carolina	3	Georgia	1
Arizona	3	Kentucky	1
California	2	Illinois	1
Florida	2	Michigan	1
Tennessee	2	Wisconsin	1
Texas	2	Iowa	1
		South Dakota	1
		Oklahoma	1

The research advisors rated all Fellows as adequately prepared for their research assignments and noted that they approached their problems with initiative and zeal. Their research contributions were graded from good to outstanding, and nearly all Fellows expressed intentions to embark on research of a similar nature to that undertaken at the NASA centers after returning to their home institutions. As a matter of fact, some of the Faculty Fellows have since submitted research proposals to NASA. The picture would be incomplete without saying that the institutes were also an extremely rewarding experience for the codirectors and that partly as a result of these institutes one of the university codirectors intends to spend his sabbatical leave next year in one of the NASA centers.

Encouraged by the success of the first three summer institutes, NASA has decided to continue the program and to expand it from three to six institutes by including the centers and universities listed in table IV. Announcements of the 1965 summer institutes have been distributed by the ASEE and the universities involved.

The three pilot institutes have invited essentially all of the 1964 Fellows to return for a second stage as orginally planned. They have also made preparations to accommodate up to 15 new Fellows each. Accordingly, the 1965 research programs of the continued institutes have been subjected to minor changes only and the new special courses will be sufficiently wide in scope to be of interest to both returning and first-year participants. Table V(a) summarizes the planned 1965 research and course programs of the three pilot institutes. Approximately one-third of the Fellows invited to return did not accept the offer primarily because they have in the meantime de-

Table IV.—New 1965 ASEE-NASA Summer Institutes

Universities	NASA centers
University of Houston Texas A & M *Codirector:* C. J. Huang Professor of Chemical Engineering University of Houston	Manned Spacecraft Center Houston, Texas *Codirector:* M. Scott Carpenter Executive Assistant to the Director Manned Spacecraft Center
Auburn University The University of Alabama *Codirector:* R. I. Vachon Associate Professor of Mechanical Engineering Auburn University Auburn, Alabama	Marshall Space Flight Center Huntsville, Alabama *Codirector:* Robert R. Head Chief Applied Mechanical Research Branch Marshall Space Flight Center
University of Maryland The Catholic University of America *Technical Program Directors:* A. B. Marcovitz Assistant Professor University of Maryland College Park, Md. Bertrand Fang Associate Professor Catholic University Washington, D.C.	Goddard Space Flight Center Greenbelt, Maryland *Technical Program Director:* Chesley H. Looney, Jr. Assistant Chief Advanced Development Division Goddard Space Flight Center

veloped their own research activity at their respective academic institutions.

The research and course programs of the new institutes summarized in table V(b) also reflect the distinctive features of the NASA centers involved. While the three pilot institutes seem to emphasize predominantly the more theoretical and scientific aspects of our aerospace efforts, the new institutes offer in addition unique opportunities for advanced engineering research and systems analysis.

As a result of these institutes, it is hoped that the faculty members will return to their universities with new ideas for future research and an increased capacity to stimulate interest among their students in aeronautics and space exploration.

Table V.—Planned Research and Course Programs of 1965 ASEE–NASA Summer Institutes

(a) Continued Institutes

Institutes and number of participants	Research areas at center	Courses offered by codirecting universities
Case-Lewis (11 returning and 10–14 new Fellows).	Selected problems associated with power generation in space and with propulsion	Lecture series on power generation and primary emphasis on: Energy sources Methods of energy conversion Electrical conditioning Heat rejection
VARC-Langley (8 returning and 15 new Fellows).	Structures Structural dynamics Materials physics Communications Fluid mechanics and aerodynamics	Special seminar-type courses in each of the 5 research areas
Stanford-Ames (9 returning and 15 new Fellows).	Space physics Fluid dynamics and gasdynamics Guidance and control Life sciences	Space Technology Seminar (8 sessions) and 4 special courses on: Space physics Singular perturbation methods in fluid mechanics Modern systems theory Engineering problems in physiology

Table V.—Planned Research and Course Programs of 1965 ASEE–NASA Summer Institutes—Concluded

(b) New Institutes

Institutes and number of participants	Research areas at center	Courses offered by codirecting universities
University of Houston, and Texas A & M, Manned Spacecraft Center (15 Fellows)	Spacecraft design Man-machine systems Biomedical engineering	Spacecraft Design Seminar and 3 special courses (30 lecture hours each) on: Space environment and materials Electrical and electronic aspects of spacecraft design Spacecraft structural analysis
Auburn University and University of Alabama, Marshall Space Flight Center (15 Fellows).	Vehicle engineering Propulsion and cryogenics engineering Guidance, control and communication	Seminar series (20 sessions) on topics related to research areas, in addition to advanced graduate courses at the Huntsville campus of the University of Alabama
University of Maryland and The Catholic University of America, Goddard Space Flight Center (15 Fellows)	Space sciences and plasma physics Tracking and data systems Communications Servo control and antennas Quantum electronics	8–10 days of workshop sessions at UM and CUA, plus lecture series on Space Sciences including: Orbital mechanics Space physics Data processing Communications

Comments—Session I

Page, *Wesleyan University:* Does the $40 000 000, described as an annual expenditure, include the step financing, committing funds of about equal amount 2 years in advance, or not?

Scott, *NASA:* I think the $40 000 000 included all three programs for the particular fiscal year discussed, in which case only the research funds would be under the step-funding principle; the training and facilities grants are not on a step-funding basis.

Predmore, *Duke University:* Has the Office of Grants and Research Contracts made or does it contemplate making a survey of the range of uses to which the universities have put the university allowance that accompanies a predoctoral training grant. I think this would be interesting and useful.

Hansing, *NASA:* We have received annual reports on the uses of the institutional allowance as part of reports of expenditures of funds. For the students who were supported at the beginning of September 1963 through August 31, 1964, this is under study now. We have not completed any analysis of this, but we are going to do this to see exactly how the universities are using these funds.

Vassamillet, *Mellon Institute:* The assumption seems to be that there are plenty of students, predoctoral material, of good quality, to fill the positions that are being made available by the increase in graduate work. Although I am not directly involved in education, my associates in the universities indicate that finding good graduate students is a real problem. Is this true?

Hansing: This question has been discussed many times. From the reports which we have received, the universities indicate that there are large numbers of good graduate students available in the various graduate schools. All the traineeships which we have awarded to the various institutions have been filled, and I don't anticipate any real problem.

Sawyer: I might make two comments on this. The first is that in our graduate school we certainly have not had a shortage of applicants either for admission or for fellowships. The second one, which is more general, is that I think the number of bachelor degrees in science

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and particularly in engineering is increasing more rapidly than the number of graduate students. Particularly in engineering there are plenty of able students who should be attracted to further graduate work and who have been in the past drained off or diverted into immediate jobs. I don't believe that we are going to run up against a shortage of capable, willing students for graduate programs with NASA.

Brotzen: We can fill the NASA fellowships very easily without decreasing any of the assistantships given by the university. The reason for it is that particularly in science and engineering there are large numbers of able students who have not attended graduate school. For example, at the present time, about 70 to 80 percent of all our graduates who receive bachelor degrees eventually attend some graduate school. Only a few years ago this number was about 50 percent. So there is a considerable increase in the number of potential graduate students.

Hansing: The proposals submitted by universities indicate that they could accept at least two or three times the allotments which we have made. I think this represents a true indication that there certainly will not be any shortage of good graduate students.

Snell, *Tulane University:* With regard to the use of the university allowance, it was indicated that no analysis has been made. However, has any use which NASA does not approve been noted? I am simply trying to find out if any of the uses I have in mind are taboo.

Hansing: We have not published a list of includable or excludable items. We are still following our original philosophy that the expenditures under the university allowance be used mainly for improving the graduate programs in the space-related areas; we would like to continue the flexibility in this policy and have the university officials use the money in the way they think best to improve the graduate programs at their institutions. I do not care to make a list of the ones we do not consider appropriate. If in a particular financial statement we should see an item that does not seem to be in line with our policy, we would contact the university to discuss the matter.

Session II—Research

Chairman: **John R. Craig, III**
Chief, Research Division
Office of Grants and Research Contracts, NASA

Coordinator: **Herbert B. Quinn, Jr.**
Office of Grants and Research Contracts, NASA

N66-12421

Research Program of MIT's Center for Space Research

John V. Harrington

CENTER FOR SPACE RESEARCH
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE CENTER FOR SPACE RESEARCH AT MIT is the newest of MIT's multidisciplinary laboratories. Its conceptual origins go back many years, but its factual beginnings date back to May 1963 when a NASA research grant was received for its support. The establishment of the Center most certainly did not mark MIT's entry into space-related research. There have been large and thriving programs at several of the Institute's larger laboratories, such as the development of deep space navigation and guidance systems at the Instrumentation Laboratory, and research on space communications, reentry phenomena, and radar astronomy at the Lincoln Laboratory. A number of quite significant campus research activities in space physics and in radio astronomy were all in being. The purpose of the Center for Space Research was not to encourage further the growth of these larger projects but to provide a focus for a very large number of much more modest tasks representative of graduate student research in a great many space-related fields. The intent was to stimulate graduate education and research in fields broadly pertinent to the national space program and to do this by providing funds, facilities, some general direction, and central administration for this new research activity.

The program to be discussed is this general research program of the Center. It is only a fraction of the space research underway at MIT but is the fraction that has been called "seed research" and is designed to encourage new ideas on the part of the faculty and graduate students working in fields pertinent to the space program.

The program is supported by an institutional grant the distribution of which is determined by the Center's administration and its associated technical and policy committees. Promising ideas can be quite promptly identified and research rapidly started to develop the ideas to the point where much larger support may be sought should this be justified. The program, although it is only about a year and a half old, has already filled in the chinks, so to speak, between areas covered by many of the larger research projects at MIT, and work in several new fields of space research has been initiated in a fairly direct and fruitful manner. This is particularly true of some topics in astrophysics, some work in exobiology, and some pertinent topics in the social sciences, all of which were not underway prior to the inception of the Center's general research program and all of which were of great interest to a number of well-qualified faculty and graduate students.

There are several measures by which one can judge the effectiveness of a program such as this. One measure, of course, is judged by the quality of the research it produces, and the program at MIT is not yet old enough to apply this criterion. A second measure is judged by the interest and cooperation it awakens among the campus researchers. From the very beginning of the MIT program, the Center has been oversubscribed insofar as the number of ideas submitted was concerned. The program included about one out of every three projects proposed, and it took some considerable selection on the part of the administrative committees of the Center to select those projects that were felt to be most important, potentially the most significant, and which represented the most worthwhile contributions to space science and technology. The program has now grown to the point where the third semiannual progress report issued just recently includes the work of some 50 faculty and 50 graduate students distributed over four major schools of the Institute.

RESEARCH THEMES

This situation of having more worthy projects to pursue than effective means with which to pursue them is a fairly common campus problem. The need to select from among these led to identifying certain themes in the broad fields of interest to the Center and essentially choosing or encouraging topics that would emphasize these themes. For example, the Center is broadly interested in the space-related research in the social sciences, the life sciences, the physical sciences, and branches of engineering, and within these broad fields has emphasized the following themes.

In the life sciences, the themes are grouped around research on nutrients for manned space flight, the growth of nutrients by microbial means, and some aspects of space biology.

In the physical sciences, various astrophysical topics are being emphasized such as studies of the interplanetary medium, the solar wind, and studies in the new field of X-ray astronomy. There are continuing studies of constituents of meteorites and tektites and mathematical studies of the hydrodynamics of the solar atmosphere and the dynamics of galaxies.

In the social sciences, the topics group around the societal implications of the national space program and the study of space research as an instrument of foreign policy. In industrial management, the principal concern is with the impact of research and development on the U.S. economy and the beginnings of some case history research on the mechanism of industrial fall-out.

In engineering, a number of themes have been identified. One concerns the behavior of materials in space where the long-term effects of either radiation or high vacuum on the structural or electronic properties of various metals are of interest. A second comprises a number of topics in fluid mechanics such as investigations of turbulent flow, free-molecular flow, and the flow of the interplanetary plasma around planets. A fairly heavy activity in space propulsion and power is also noted; included here are topics in magneto-hydrodynamics, gaseous nuclear rockets, supersonic combustion in rockets, direct conversion of energy from radioisotopes, heat-balance studies in nuclear rockets, and certain aspects of fuel-cell research. Finally, there are some topics that center around control and include theoretical studies in nonlinear control systems, optimization methods for closed-loop systems, and chemical control systems for the regeneration of spacecraft atmospheres.

LARGER RESEARCH TASKS

All of these subjects are excellent sources of thesis research, principally at the doctoral level and, as individual topics, command the attention of perhaps one or two graduate students and a faculty member. There are also associated with the Center, and in some cases administered by the Center, larger research projects that have their own direct support and in a sense represent the next stage in the development of an idea into a larger research program. These are tasks that are still undertaken by faculty and graduate students but require a somewhat more organized and larger effort. For example, there is a large program of research in the communication sciences as applied to space underway in the Research Laboratory of Electronics, a program in space electronics, research on solid-state energy-conversion processes, research in psychobiology, fundamental research in space navigation and guidance systems, and a large effort in space physics devoted principally to an experimental study of the interplanetary medium.

EXPERIMENTS IN SPACE

A third activity of the Center, and a new facility for the campus, is the establishment of a laboratory for undertaking experiments in space. This is regarded as a particularly important part of the stimulation of the campus researcher to undertake research in space-related fields. Without the opportunity to make realistic measurements in space, the research he does, particularly in the physical sciences, will be sterile and perhaps less exciting. The Center's Laboratory for Space Experiments is staffed with full-time researchers, who have competence in the development of instrumentation to be placed on space vehicles. The work thus far has included the development of probes to measure the interplanetary plasma and, as such, represents a continuation of work started some time ago by the MIT cosmic ray group with the help of the Lincoln Laboratory. New and more extensive measurements of the interplanetary medium are being planned. There is an active program to develop a plasma probe for the Anchored IMP satellite. The development of a gamma-ray telescope to be placed aboard an orbiting astronomical observatory is just about completed, and there is the development of an X-ray telescope to be flown by a balloon above the terrestrial atmosphere to observe X-ray sources in the galaxy. Finally, there is also the early study of a novel means for probing the extended solar corona by a radio-transmission method that eventually might lead to the development of a complete, albeit small, payload. The spacecraft involved here is physically small enough to be handled readily by a small laboratory, but the problems it presents are comprehensive and are drawn from many fields and offer excellent opportunities for a variety of realistic space-related thesis research.

This latter program is a good example of the kind of unifying or focusing effect that a more comprehensive research project can bring to the Center's otherwise diverse activities. Some eight or nine researchers from many different departments at the Institute are involved in this solar-probe study. Members of the Physics Department, the Aeronautics and Astronautics Department, and the Electrical Engineering Department are participating, as is a member of the Political Science Department, because of the likelihood of modest members of foreign scientists cooperating on aspects of this program. In this connection it is hoped that the larger research programs of the Center will provide useful case history experience for the social scientists on campus who are interested in the genesis of a space research task and its eventual growth in the international scientific community.

DETAILED EXAMPLES

With this as a general outline of the Center's research program, the specific tasks being supported under this grant will be described in detail in order to give a somewhat clearer view of the kind of research encouraged, the departmental participation in the program, and the relatedness of the research to some important larger problems in space science and technology.

One of the larger, specifically funded projects is an investigation of solid-state energy-conversion processes that is being undertaken by the faculty from the Department of Electrical Engineering. It is oriented toward the fundamental problems of photovoltaic and thermoelectric energy-conversion processes involved in the utilization of solar energy in space applications. Such subtopics as the measurement of the optical absorption edge in cadmium telluride, the determination of the thermal and electronic transport properties of zinc antimonide, and, most importantly, investigations of a graded-energy-gap photovoltaic device are included. There is some hope, that a graded-energy-gap solar cell would be somewhat less susceptible to radiation damage than the more conventional cells. An investigation of multitransition pn junction solar cells that have the promise of much higher conversion efficiency is also underway.

In the Department of Geophysics there has been underway for some time work in the measurement of the strontium 87-strontium 86 ratio and the rubidium-strontium ratio of various rock samples. The Center's grant has made possible an expansion of this work, placing emphasis on the dating of meteoritic material with a view eventually to determining its geologic history.

There are a number of problems in astrophysics of a hydrodynamical nature that have been under study for sometime by members of the Mathematics Department. The support from our blanket grant made possible the expansion of this work to study convection processes in the solar atmosphere as well as problems of gravitational instabilities associated with the familiar spiral arms and spiral patterns of certain galaxies.

The study of the interplanetary plasma flow around planets has been undertaken by the faculty in the Aeronautics and Astronautics Department to supplement the direct measurements and theoretical work of a group in the Physics Department, who have been measuring the interaction of the solar wind with the Earth's magnetosphere.

Also, in the Department of Aeronautics and Astronautics a series of studies concerning the flow around electrodes in magnetogasdynamic generators and accelerators is underway. These are problems that are fundamental to interpretation of the operating behavior of magnetogasdynamic generators that, in turn, appear to be important elements of future spacecraft power systems.

In the Department of Meteorology, experimental work is being done on the investigation of the stability of shear flows. The study of turbulent flow is of importance in both upper atmospheric air motions and in interplanetary gas flow as well.

There are fundamental studies being made of gaseous nuclear rockets in the Department of Aeronautics and Astronautics. The basic idea here is to investigate vortex flow as a means of containing a fissionable gas in contact with a light gaseous propellant. The eventual objective would be the development of a very lightweight, highly efficient heat exchanger and, hence, a lightweight nuclear-powered rocket motor. Obviously, the eventual construction of such a machine would be well beyond the scope of a campus general research program, but the fundamental ideas involved are not. The fundamentals of vortex containment are being experimentally investigated in order that the soundness of this kind of gaseous nuclear rocket may be established.

Also in fluid dynamics, this time within the Department of Mechanical Engineering, is an investigation of free-molecular-flow fields with particular emphasis on gases ejected from bodies in space, and, problems in high-vacuum pumps and systems.

In the same department there is also fundamental research on supersonic combustion. Here the eventual objective is to understand the fluid-mechanic–chemical-kinetic interactions that permit the existence of chemical reaction rates of sufficient magnitude to produce sustained supersonic combustion waves. The application to combustion processes in rocket engines is obvious.

Again in the same department, studies on the effect of axial heat flux distribution in heat exchangers are underway. The important objective is to study the so-called burnout or critical heat flux that is associated with the sharp reduction in ability to transfer heat from the heated surface. These studies have application to the design of space nuclear reactors and heat exchangers.

In the Department of Chemical Engineering there are a number of problems in radiative heat transfer being studied that are focused on the measurement of soot concentrations in hot combustion gases and rocket exhausts. The development of light scattering as a tool for measuring these concentrations and the determination of the optical properties of the soot and the measurement of the particle distributions in a turbulent flame are all of concern. Out of this might come a better diagnostic tool and a better understanding of the chemical-kinetic processes governing the performance of rocket engines.

Also in the Chemical Engineering Department research is underway on fuel-cell developments for space power systems. Of particular concern is the behavior of the electrodes through which the electrolyte containing both fuel and oxidant is caused to flow.

Again, in the Department of Chemical Engineering, with some cooperation from the faculty in the Electrical Engineering Department, a fundamental study is being made of microwave-induced chemical reactions. The idea is to use microwave energy to yield desirable chemical end products that have some application to space technology, for example, studies of the synthesis of hydrazine from ammonia.

In the same department environmental control systems that can remove carbon dioxide from an atmosphere and simultaneously resupply pure oxygen are being investigated. The fundamental processes of concern here are chemical adsorption and absorption.

In the Department of Electrical Engineering, a number of faculty are working on the foundations of a theory of nonlinear systems and circuits that would have application to several closed-loop control problems occurring in the control of rockets and spacecraft.

In the Department of Nuclear Engineering, the Center's grant is supporting research on neutral-beam production, where the object is to study the production of high-energy beams of neutral atoms. There is a larger project on the analysis of reactor physics and heat transfer in nuclear-rocket reactors. The emphasis here is on the start up of rocket-reactor cores and also on rocket-reactor shielding. Both of these questions are fundamental to the eventual development of practical space reactors and are susceptible to study either theoretically or experimentally with the aid of such facilities as the MIT nuclear reactor.

Research is also being done on the direct conversion of energy from radioisotope power sources. This project has some particularly exciting possibilities in the sense that the energy released by radioisotope decay is essentially all in the form of kinetic energy of charge particles. If this can be directly converted, for example, by deceleration in an electric field, a very efficient conversion process is potentially available that promises great increases in the specific power of radioisotope-fueled space power systems. The present radioisotope power sources all depend on conversion to heat energy as an intermediate step and are characterized by very poor overall efficiencies.

There are a number of projects in the Department of Metallurgy concerned with the general study of materials for space applications. The first of these projects is research on the mechanism of texture-hardening in metals, which has great application to the understanding of fatigue failure in spacecraft and booster materials. Studies on the effects of space radiation on electronic materials center around the irradiation of bismuth telluride and the measurement of its Hall coefficient and resistivity as a function of radiation dosage.

Similarly, a study is being made of the surface behavior of certain refractory solids when exposed to extreme variations in pressure. Such questions as the adsorption of gases on surfaces and the dependence of this process on the surface treatment and changes in environment are being investigated.

A very important project on the diffusion of volatile metals through nonvolatile materials at low pressures is also underway. These studies are fundamental but have applications to such important space technology problems as the containment and storage of liquid hydrogen propellants.

While most of the work in the general research program is theoretical or, in only a modest sense, experimental, in certain instances the development of slightly larger experimental facilities has been supported where they would clearly be of use to a number of researchers for a variety of investigations. For example, a large-flow-rate thermal-plasma source that can supply, for about 1 minute, up to 2 kilograms per second of argon heated to a stagnation temperature of 2000° K was designed by the faculty in the Aeronautics and Astronautics Department and has been built largely with graduate-student help. This source should be operating shortly and will be available for a number of fundamental studies in magnetogasdynamics and basic investigations of properties of plasmas.

The grant also supports theoretical work in the kinetic theory of plasmas in this same department that is oriented toward the study of irreversible behavior of plasmas and the understanding of so-called microinstabilities of plasma oscillations.

The faculty of the Department of Electrical Engineering are working on a large, separately supported project on research in space electronics. The tasks include an investigation of conduction processes in thin films and research on the computer-aided design of space electronic circuits. This is another example of one of the large specific projects that is, in a sense, buckled to the Center's general grant and that influences and is influenced by the general research program.

In this same department, the Center's grant is supporting theoretical investigations of minimum fuel systems including an investigation of satellite attitude controls from the viewpoint of minimizing a combination of the consumed fuel and response time.

An additional and quite pertinent extensive project buckled to the large Center grant is support for research in the communication sciences that is undertaken by the Research Laboratory for Electronics. It covers a large number of topics from linguistics to the processing and transferring of information pertinent to space communications, in some measure, interact with the Center's general program.

In the social sciences, a broad study is underway on the impact of research and development on the U.S. economy. The study has been broken down into three parts: the first involves a comparison of the postwar economy; and the third will consider the future role of relarge, relative to the first few decades of this century when they were small; the second will use these comparisons in an attempt to evaluate specific effects of research and development on the functioning of the postwar economy; and the third will consider the future roll of research and development and the ways in which a better understanding of its impact can maximize its future usefulness. This work is being done by the faculty of the Sloan School of Management.

The faculty from the Department of Economics and Political Science are undertaking a number of studies concerned with public policy aspects of space research. These include (1) the scientific and technological aspects of policy-making in foreign affairs and (2) the opportunities offered by science and technology for creative policy initiatives. This group has recently undertaken a general study of sponsored research activities at MIT to understand somewhat better the research process. These investigations use MIT case histories, but they are throwing considerable light on the impact of large mission-oriented support on research choices made by individuals and groups working in an academic context.

The Center's general grant has had a great deal to do with the growth of an important space-related program of research in the life sciences at MIT. There is a large, separately supported program of research in psychobiology undertaken by the faculty of the Department of Psychology, the support of which is buckled to the general grant. The studies are quite fundamental and concern three areas of the brain and behavior, perception and learning, and social-developmental psychology. These topics have application to manned space flight, particularly to the behavior of man under stress.

In the Department of Biology, research on information transfer in prebiological environments has been initiated with the aid of the general grant of the Center. This is an initial project in exobiology and is concerned with the important chemical reactions necessary for the emergence of life on this planet. There is a general interest in exploring genetic information-transferring mechanisms and in exploring ways in which this information transfer may be carried out in environments that differ from the Earth's. There is also work on enzymatic systems involved in fixation of nitrogen by microorganisms—a process of fundamental interest in producing a necessary constituent of living matter.

In the Department of Food Science and Technology, research aimed at the selection of microbial mutants in closed systems is underway. The eventual application is to the production of nutrients for manned space flight.

In the same department, studies of muscular exercise is a means of preserving muscle mass during prolonged confinement and its effect on increasing protein and amino acid requirements are underway. Here, the concern is that increased exercise to preserve muscle tone might result in increased food requirements and increased payloads, and these interrelations are being studied. There is also work on the development of a synthetic diet for certain nutrition and metabolism experiments that have direct bearing on manned space flight.

Finally, in the same department, a project on the production of edible proteins of microbial origin is underway. Here, the objective is the growth of edible protein by means of vegetative cells. The short-term objectives of this program are to determine the approximate composition of the cells and the various methods of processing that would be suitable for the isolation of various cell components as edible material.

SUMMARY

The Center's research program is composed of three major segments that are approximately equal in a support sense.

The first is a program of general space-related research, which is described in some detail and which covers almost all of the major disciplines pertinent to the national space program in which there is competence at MIT. It includes the work of some 50 faculty members and a like number of graduate students and is composed of some 40 individual research tasks.

The second component of the program is a group of larger tasks, perhaps six or more ranging from space electronics to psychobiology, which, in a technical sense, are more loosely affiliated with the Center but are partly administered by it.

The third component is a growing program of experiments in space with particular emphasis on research in the space sciences, the measurement of the interplanetary plasma, the characteristics of the extended solar corona, gamma-ray and X-ray astronomy, and more recently, some work in solar radar astronomy. A considerable effort is involved here, but out of it also have come and will come some of the most exciting and important contributions to our knowledge of the space environment.

All of the work provides opportunity for challenging graduate student research, and it is hoped in that sense the research program will also contribute directly to the training of well-qualified engineers and scientists who will help fulfill the nation's ambitions in space.

COMMENTS

Smull, *NASA:* You indicated that the program you discussed at the beginning of your paper had not been under way long enough to assess the value of it or the accomplishments. What steps are being taken to see, as time goes on and you begin to assess this program, that it develops into a dynamic activity and that those segments of your program which may not be so promising do not become static?

Harrington: What I meant was that it is too early for research results to be assessed with any degree of accuracy. It certainly isn't too early continually to examine the program and make sure that the potential is still good. There are a series of publications on all the usual criteria by which one judges the health of a program, but what I was referring to was really the longer term output, the quality of the ideas that emerge. I think it is too early for that.

Summerfield, *Princeton University:* I gather that the Center operates in large measure by receiving proposals from various departments of the university and that these are then evaluated and funded according to their merits and according to the objectives of NASA. As I understand it, you have three times as many proposals as you can possibly fund, so immediately you are confronted with an evaluation problem and a reviewing problem, and, of course, a competition problem. How do you handle this?

Also, is there a scheme for assigning to each department a certain budget and allowing each department to determine for its field what is the most worthy of the several proposals that it may have available? Finally, the question occurs: why would a professor come to the Center when he could deal with—and enjoy a good working relationship with—NASA directly?

Harrington: The Center has a policy committee composed of the deans of the various schools and a technical committee composed of senior faculty from all the major departments of concern. When we receive a suggestion from a faculty member or a graduate student, this member or student and his work are well known to many members of our technical committee and a quick determination both of the quality of the idea and of the probable outcome can be made.

The choice of going to the Center's general pool instead of going directly to NASA is the individual's. He needn't approach us unless he wishes to do so. The decision is usually based on the size or scope of what he wishes to do. If he plans to undertake a fairly modest project or perhaps measure it in terms of, say, a $10 000 budget, he generally will come to us because he could be started on this very quickly if our committee thought his project a good one, whereas a much longer initiation cycle is involved in going to NASA. For much larger activities, perhaps five times this one, the Center would not be the place to come. We are interested in the more modest projects, the newer ideas, the seed research.

Smull: As I mentioned previously, this is another manner which NASA uses to support research. Research support by NASA in fiscal year 1964 was about $50 million, of which about $42 to $43 million was the project-type research Dr. Summerfield mentioned. The type of activity described by Dr. Harrington accounted for $7 million.

Collins, *University of Minnesota:* Is there any sort of a time limit? How long can an investigation be continued through your central pool?

Harrington: We don't have any fixed operating rule for that but, in general, we would expect the idea to grow—after a period of time, say about a year or two—or be discontinued.

Zucrow, *Purdue University:* Suppose a potential investigator makes a proposal to this committee and it is turned down. What does he do if he still believes he has a good idea?

Harrington: He would still have the privilege of going directly to the agency.

Craig: Any researcher can approach NASA on an individual basis. Also, there are the National Science Foundation, the Defense Department and others.

Harrington: The Center now takes care of about one-third of MIT's space-related research, so two-thirds of our colleagues have found the direct route more attractive.

Zucrow: What is your budget per year?

Harrington: The Center's budget runs $3 million a year.

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Interdisciplinary Research in Theoretical Chemistry

Joseph O. Hirschfelder

THE HOMER D. ADKINS PROFESSOR OF CHEMISTRY
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AT THE UNIVERSITY OF WISCONSIN we have had the opportunity of setting up with NASA support a Theoretical Chemistry Institute with sufficient competence, vigor, and financial support to play a major role in the development of molecular quantum and statistical mechanics. Theoretical chemistry seeks to determine the physical and chemical properties of materials, to relate these macroscopic properties to the individual molecules, and to determine the structure and properties of the individual molecules. At the present time, *all* the required fundamental laws of nature are sufficiently well known. Thus, we can write down the mathematical relations which describe the physical and chemical properties. Then the problem becomes one of determining the solutions of the mathematical equations. Because of the development of new methods of solution of nonlinear mathematical problems, because of a greater insight into the basic workings of molecular quantum mechanics and the kinetic theory of gases, and because of the availability of gigantic high speed computing machines, theoretical chemistry is making very rapid and exciting progress.

Theoretical chemistry is a natural focal point for interdisciplinary research since its problem areas overlap with physics, mathematics, astronomy, meteorology, chemical engineering, mechanical engineering, etc. In relating the macroscopic properties to the individual molecules, we serve as the "middlemen" between the theoretical physicists and the practical engineers and experimental scientists. Under normal experimental conditions with normal substances, the usual engineering equations suffice. But the usual engineering equations do not

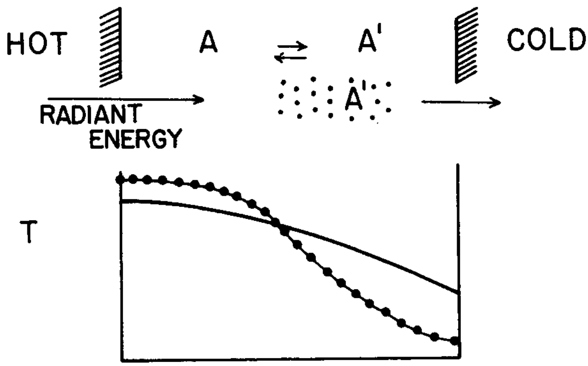

Figure 1.—Example of molecular "feedback" mechanism at very high temperatures.

suffice under extreme conditions, such as are encountered in: (1) the highly ionized almost vacuum of the upper atmosphere; (2) the high temperature shock wave preceding a reentering nosecone, (3) the high pressure high temperature combustion gases in a rocket motor, (4) the partially ionized plasma of a nuclear reactor motor, or (5) metal fatigue. Under extreme conditions, where reliable experimental data are hard to obtain, theoretical predictions are useful. Under extreme conditions, the coupling becomes strong between the macroscopic and the molecular properties. For example, consider figure 1. On the left is a hot plate from which radiant energy emerges into a region containing a reacting mixture of transparent normal molecules A and opaque electronically excited molecules A'. The temperature contour is shown by the solid line. A small increase in the temperature of the hot plate might produce the temperature contour shown by the dotted line of solid circles. The small increase in radiant energy near the hot plate might produce a correspondingly small increase in the number of electronically excited molecules, which being opaque to the radiation might produce a large change in the opacity, which might produce a large change in the radiant energy flux, and which finally might produce a large change in the local temperature. The temperature of the cold wall might even be decreased as shown in the figure. Kantrowitz, Kivlin, and their Avco associates did a masterful job of considering such problems in connection with nosecones reentering the atmosphere.

Because of such "feedback" mechanisms involving molecular properties, the equations of change of macroscopic properties become nonlinear under extreme conditions. The usual engineering equations apply to the linear Hooke's law regions, but it takes a deeper understanding to cope with materials near the fracture point. Thus, the more we can learn about the individual molecules, the better we can serve as "middlemen" to help the space scientists to cope with unusual environments.

Our group at the University of Wisconsin contains 8 professors, 10 postdoctoral research associates, 26 graduate students, and 4 computing programers. Our staff contains experts in quantum mechanics, statistical mechanics, electromagnetic theory, molecular beams, biochemistry, and numerical analysis. The quantum mechanics is used to determine the structure and properties of the molecules. The statistical mechanics determines the coupling between the molecular and macroscopic properties. The electromagnetic theory is required for plasma and radiation problems. The molecular beams furnish the simplest examples of chemical reactions and simulate the sort of collision processes that occur in the upper atmosphere. Our biochemical program (supported by the National Institutes of Health) is intended to apply molecular theory to biological systems. The numerical analysis is required for the solution of a large percentage of our complex problems. At the present time our emphasis is on improving the mathematical methods. Gradually, as our understanding and techniques improve, we hope to shift the emphasis towards the applications.

SUMMARY OF CURRENT RESEARCH

QUANTUM CHEMISTRY

Our main interest at present is in finding new approaches and techniques, rather than in large-scale computing based on existing methods. The principal difficulty in solving the Schrödinger equation for a molecular system stems from electron correlations. We are applying perturbation theory to this problem, with the object of calculating molecular energies, other molecular properties, and intermolecular forces. The basic theory is contained in a review article which we have recently published (ref. 1). Scherr and Knight (refs. 2 and 3) have shown that perturbation theory can be used to calculate the energy of formation of the ground state of the helium atom to any desired precision. Lyon, Matcha, Sanders, Meath, and Hirschfelder (ref. 4) have shown, for the ground state of the diatomic hydrogen ion, that an approximate wave function corrected by first-order perturbation is quite accurate throughout configuration space and its energy expectation value is comparable to or better than the best variational calculations. Within the last month Matcha and Byers Brown (unpublished data) have calculated the energy of the ground state of the hydrogen molecule through the fifth order and found that it agrees with the exact energy to within a hundredth of an electron volt. Thus we feel confident that perturbation theory is workable and is capable of giving the precision which we require.

However, research at the Institute is not limited to one approach or one area. Other topics being studied include the Auger effect, the united atom approach to molecules, natural spin orbitals, and correlated wave functions. The long-term goal for the future is to be able to obtain molecular properties and interactions with sufficient accuracy to obtain cross sections for energy transfer and chemical reactions and to carry out completely theoretical calculations of bulk properties, both for equilibrium and for transport.

Byers Brown (ref. 5) has shown that, even at small separations, the energy of interaction of two atoms is not an analytic function of their separation but contains a term $R^5 \log R$. This result will have considerable repercussions on the "united-atom" approach to molecular quantum mechanics.

Particularly interesting is the application of "hypervirials." Epstein and Hirschfelder discovered an infinite set of generalized virial theorems (refs. 6 to 14) which are valid in classical mechanics, relativity, and quantum mechanics. The relations are very simple. If H is the Hamiltonian for the system and W is a function of the coordinates and momenta (but not a function of the time) then, in classical mechanics, the time average over a trajectory of the Poisson bracket (H,W) is equal to zero. In quantum mechanics the equivalent theorem is that the expectation value of the commutator $[H,W]$ is zero. The quantum mechanical relation is the diagonal element of the Heisenberg equation of change in the energy representation. For example, if W were equal to the scalar product of the Cartesian coordinates and the momenta, the hypervirial relation would be the usual virial theorem. Considering any other function W, we obtain a new dynamic relation which must be satisfied by the wave function or the trajectory. In quantum mechanics, an approximate wave function φ which satisfied the hypervirial relation is energetically stationary with respect to variations of the type $\varphi \rightarrow \varphi + i\lambda W \varphi$. Here λ is a small variational parameter and W is assumed to be Hermitian. In classical mechanics an approximate trajectory satisfying the hypervirial theorem is stationary or stable with respect to infinitesimal contact transformations generated by $\lambda\ W$, that is

$$q_j(t) \rightarrow q_j(t) + \lambda \frac{\partial W}{\partial p_j}$$

$$p_j(t) \rightarrow p_j(t) - \lambda \frac{\partial W}{\partial q_j}$$

The quantum mechanical hypervirial theorem has been used to:

(1) Help in the determination of approximate wave functions

(2) Provide variational principles which can be used in the determination of scattering cross sections
(3) Help in the determination of expectation values of properties other than energy

In reference 14, Robinson has shown that the satisfaction of a particular hypervirial relation is equivalent to requiring that the first-order perturbation correction to the expectation value vanishes. Indeed there is a very close connection between perturbation theory and the use of hypervirials which we are exploring.

There are a great many applications of the classical hypervirial theorems which should be exploited. Lord Rayleigh (ref. 15) used a generalization of the virial theorem (a particularly simple type of hyperviral corresponding to $W=xp_y+yp_x$) to determine the stability of struts in building members and bridges. At the suggestion of Chandrasekhar (refs. 17 to 20) Parker (ref. 16) formalized Lord Rayleigh's "tensorial-virial" relations and used them to make a crude derivation of the Navier-Stokes equations and to develop a theory for diffusion in gases. Chandrasekhar developed a form of hypervirial relations in connection with the theory of Newtonian gravitation (using "tensorial superpotentials") and found these relations useful in considering the condensation of nebulae. I am sure that classical hypervirials could be used in the rigorous determination of transport properties in gases. They might also be useful in the determination of satellite trajectories.

STATISTICAL MECHANICS AND TRANSPORT PHENOMENA

There has been a continuing study of the theory of transport phenomena or the statistical mechanics of nonequilibrium gaseous systems by C. F. Curtiss and F. C. Andrews. Background material for this work is given in a treatise on molecular theory of gases and liquids by Hirschfelder, Curtiss, and Bird (ref. 21). The adaptation of this treatment to engineering problems is given by R. B. Bird, W. E. Stewart, and E. N. Lightfoot (ref. 22). The basic problem is the relation of macroscopic constants, which describe the rate of approach of the system to equilibrium (ref. 23) to the properties of the individual molecules and the potential energy of interaction between the molecules. We seek to remove the various limitations of the well-developed kinetic theory of low density gases made up of spherical molecules. Thus, we are determining the effects of rotational degrees of freedom (ref. 24) of nonspherical molecules; we are extending the theory to moderately dense gases (refs. 25 to 30); and we are finding the quantum effects (refs. 31 and 32) at moderately low temperatures.

The properties of gases at low to moderate densities are complicated

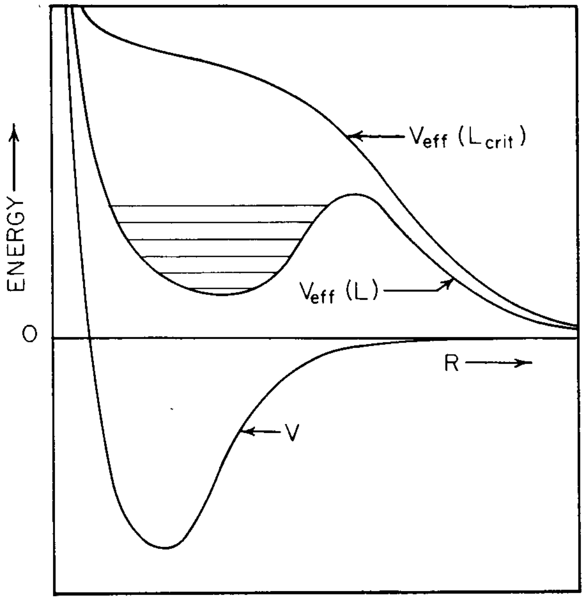

Figure 2.—Energy of interaction of two molecules as a function of their separation *R* showing metastable double molecule energy levels. Here V_{eff} is the effective interaction potential which is the sum of the true potential *V* and the centrifugal potential.

by the presence of metastable double molecules (refs. 25 and 26). Figure 2 shows how these metastable double molecules arise. Here V is the potential energy of interaction of two molecules as a function of their separation R. However, in a collision, the relative motion of the two molecules can be treated as though there were only a single particle having an effective mass $\mu = m_1 m_2/(m_1+m_2)$ moving in one dimension in the field of an effective potential V_{eff}. The effective potential is the sum of the true potential V and the centrifugal potential. The centrifugal potential is the square of the angular momentum L divided by twice the moment of inertia of the molecular pair. For small values of the angular momentum, V_{eff} has an energy hump which disappears when the angular momentum is larger than L_{crit}. In the pocket formed by the energy hump, there are energy levels corresponding to energy-rich metastable double molecules. From the standpoint of classical mechanics, these double molecules are stable until they suffer collisions with other molecules. However, from the standpoint of quantum mechanics they can break apart by tunneling through the energy hump. Which mechanism is the more important depends upon whether the quantum mechanical lifetime of the isolated double molecule is long or short compared to the average time between collisions. At very low pressure, the quantum mechanical dissociation becomes dominant. Three of the effects of metastable double molecules are:

(1) The pressure dependence of the thermal conductivity of a

gas at low to medium density is mainly due to the energy-rich metastable double molecules, formed in one place by a three-body collision, diffusing to another place where they collide with a molecule and release their energy (refs. 25 to 30 and 33). The anomalous heat conductivity of NO_2 is a specially good example of this effect.

(2) Metastable double molecules often lead to unexpected shifts in molecular spectra at high pressures (refs. 34 and 35).

(3) Curtiss is currently investigating the contribution of the metastable double molecules to the transport properties at low pressures. Quantum mechanical calculations of the collision cross sections take the metastable states into consideration (in the calculations of the phase shifts), but the classical calculations have ignored the metastable double molecules. Which treatment is right? Large errors in the low temperature transport coefficients could result from treating the metastable double molecules incorrectly.

MOLECULAR BEAMS AND SCATTERING THEORY

Recent developments in the techniques of molecular beam scattering have made it possible to study in detail the intermolecular collision processes, thus providing a deeper insight into the mechanism underlying chemical reactions. A survey of these developments is given in a review article (ref. 36). R. B. Bernstein and his associates are conducting both theoretical and experimental research on molecular beam scattering. Much of the current theoretical work is directed toward an understanding of inelastic scattering of small molecules. Both time-independent (S-matrix) and time-dependent perturbation methods (e.g., the "sudden" approximation) are being investigated. The objective is to develop methods for predicting the cross sections (and rates) for inelastic and reactive molecular collisions.

Bernstein and his associates have been computing the rotational transition probabilities for individual rotational states as a function of the impact parameter for various collisional energies. They have considered the interaction between a polar diatomic molecule and an atom in an S state. Using the "sudden" approximation, their computations have shown that, except for small impact parameter collisions, the results are insensitive to the repulsive parts of the interaction potential. Also, the *total* inelastic cross section may be approximated from a knowledge of the attractive forces and their anisotropies. Specific calculations have been made for collisions between thallium fluoride and argon, which are to be compared with experimental data. Calculations are being started on the rotational excitation of nitrogen molecules by collision with argon atoms.

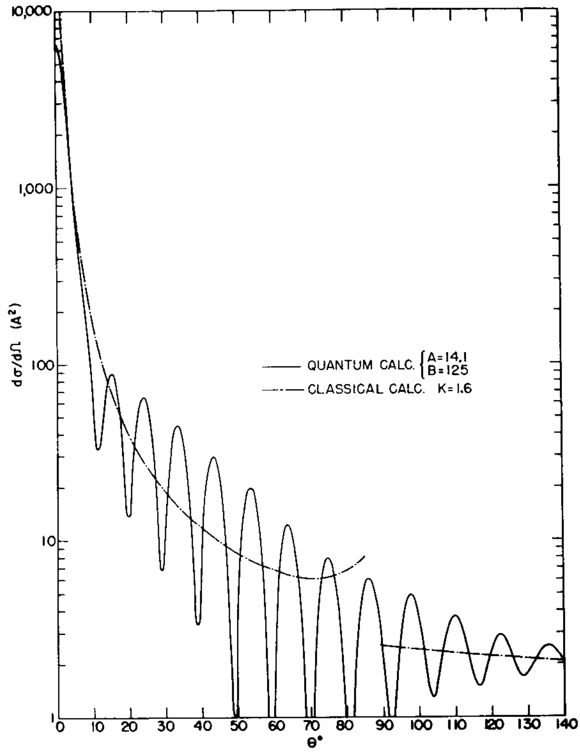

Figure 3.—Comparison of quantum and classical differential cross section as a function of scattering angle. *(Taken from ref. 38.)*

The wave-nature of matter is clearly revealed by the oscillations in the molecular beam scattering cross sections. Experiments are now available showing these quantum effects (ref. 37). Figure 3 shows a comparison between the quantum and the classical differential cross sections as a function of scattering angle for the mercury-molecular-hydrogen system (ref. 38) at a reduced kinetic energy of 1.6. For this system the quantum parameter is $\Lambda^*=0.56$. Here $\Lambda^*=h/(2\mu\epsilon)^{1/2}$ where μ is the reduced mass and ϵ is the maximum energy of attraction. Bernstein (refs. 36 and 38) has shown that if the value of Λ^* were reduced towards its classical limit of zero, the period of the oscillations would approach zero but the finite amplitude would persist. Wood and Curtiss (ref. 32) proved a closely related theorem. Thus, it is only in the sense of a smoothed average that the quantum mechanical results approach the classical.

APPLICATIONS OF QUANTUM AND STATISTICAL MECHANICS TO BIOLOGICAL PROBLEMS

A long range program has been undertaken to develop inter- and intra-molecular forces in systems of biological importance. From a knowledge of these forces, the structure and physical properties of biological systems can be determined by statistical mechanical methods.

GENERAL DISCUSSION

We believe that there are two principal advantages in having a group as large as ours: First of all, we can provide broad training for our students so that they become familiar with each of the many steps required to apply theoretical physics to practical chemical and physical problems. Secondly, when difficulties are encountered, we can get help from a colleague. Our people enjoy talking to each other and they stimulate each other. This is probably the best indication of the success of our group organization. To keep the group operating effectively, we have adopted the following principles: (1) administrative decisions are decided in a democratic manner; (2) all staff members are expected to carry a resasonable teaching load; (3) all staff members get an equitable share of graduate students and postdoctorates; (4) care must be taken to insure that each person receives proper credit for his contributions to publications.

In July of 1962 we received a grant from NASA with assurance that, if we tended to business, our research was successful, and Congress was generous, this grant would be augmented from year to year. Thus, the Theoretical Chemistry Institute came into existence. Administratively, it reports to the dean of letters and science and, for some purposes, it is regarded as a part of the chemistry department. Our professors hold joint appointments with various university departments: Epstein is professor of physics, Lovell is assistant professor of computer sciences, while Andrews, Bernstein, Byers Brown, Curtiss, Harriman, and Hirschfelder hold appointments in chemistry. The University of Wisconsin pays the full academic salaries for some of these men and the teaching aliquot of the salaries of the other men. The long-range feature of our NASA support enables our group to function effectively. Before 1962, we had year to year government contracts which enabled us to hire postdoctoral project associates, but we could not hire senior personnel and provide them with tenure. Thus, we had a continuous rotation of personnel; we were not able to develop group know-how; and we could not make long-range plans for our research. NASA support has given us stability and an opportunity to tackle the research "bottlenecks" which require continuous effort over a long period of time.

At the University of Wisconsin there are not interdepartmental barriers. We have fine working relations with many departments. For example:

(1) The Army Mathematics Research Center has arranged a symposium jointly with the Theoretical Chemistry Institute

entitled "Pertubation Theory and its Applications in Quantum Mechanics" (Madison, Wisconsin, October 4–6, 1965). The subject matter is based upon our mathematical interests and needs. The Army Mathematics Research Center is cooperating with us in many ways. Our staff attends and participates in many of their seminars. In the spring of 1965 one of their visiting professors (J. B. McLeod from Oxford) is giving a lecture series on *The Mathematics Behind the Schrödinger Equation* to our students and staff. In the summer of 1965 P. D. Robinson and Arnold Arthurs are coming from the University of York, England, to spend 3 months and a year, respectively, as joint visiting professors in the Army Mathematics Research Center and our Theoretical Chemistry Institute. The Army Mathematics Research staff has been very effective in helping us with our mathematical difficulties.

(2) We feel very close to the chemical engineering department. R. Byron Bird, its chairman, is a coauthor with C. F. Curtiss and myself of our treatise *Molecular Theory of Gases and Liquids.* We have many interests in common including: (a) the kinetic theory of gases, (b) aero- or fluid dynamics generalized to include chemical reactions, and (c) heat transfer in chemically reacting mixtures. Many of the chemical engineering students take courses in theoretical chemistry, and we frequently participate in each other's seminars.

(3) Professors Phillip Myers and Otto Uyehara of the mechanical engineering department are interested in the theory of propagation of flames and detonations which Professor Curtiss and I developed in connection with the Navy Bumblebee ram-jet program. Two years ago, the American Society of Mechanical Engineers awarded me an Honorary Life Membership as an indication that their members find our work useful.

(4) Some members of the astronomy, meteorology, physics, and theoretical chemistry groups are interested in problems of the upper atmosphere. We have joined forces in trying to bring a famous upper-atmosphere astrophysicist to Wisconsin. Gradually we hope to establish close working relations where we can pool our knowledge and know-how.

Training in theoretical chemistry provides a broad foundation for research in a wide variety of fields. There are many theoretical chemists who have shown great breadth of interests—for example, Peter Debye, Henry Eyring, Kack Kirkwood, Ilya Prigogine, and George Kimball. Others are:

(1) R. H. Wentorf invented the process for synthesizing diamonds at General Electric. Subsequently he discovered borazone, a

substance harder than diamonds. And now he is being awarded the Ipatieff prize of the American Chemical Society.

(2) F. T. McClure was awarded by President Kennedy NASA's most distinguished medal for inventing the Transit navigational satellite.

(3) Paul Knaplund, Jr., has become vice-president of I.B.M. in charge of Advanced Research.

(4) Sam Loshaek has become research director of Borden Company.

(5) Don Jepsen has been working with Montroll at I.B.M. on applying statistical mechanics to traffic control problems.

(6) Hugh Hulburt, John Dahler, and R. B. Bird have become distinguished professors of chemical engineering at Northwestern, Minnesota, and Wisconsin, respectively. Howard Palmer is professor of combustion technology at Penn State and Roger Strehlow is professor of aeronautical engineering at Illinois. Alfred Ingersoll is dean of engineering at the University of Southern California and James Hornig is dean of research at Dartmouth.

During World War II, many of us worked on military problems. We were assigned to task forces composed of engineers and scientists having very different backgrounds. We pooled our knowledge and know-how and solved problems that none of us individually could have coped with. For example, a large group headed by Charles Curtiss, Richard Kershner, and myself developed the first system of interior ballistics of guns which was thermodynamically consistent. We took into account the heat transfer from the powder gas to the surface of the bore—this is not important in a large cannon, but in an elephant rifle 30 times as much energy can go into heating the bore as goes into pushing the bullet! Later, at Los Alamos, John Magee and our Weapons Effect Group studied the kinetics of formation of industrial carbon black, the micromeritic behavior of different types of smoke, and the physics of the blown sand over the Sahara desert. Thus we were able to make an accurate prediction of fall-out while the first atom bomb was still on the drawing board. At Bikini, as chief phenomenologist, I had to work with military and scientific groups to predict the blast pressure as a function of distance, the light intensity as a function of time, the effects of nuclear radiation on beer, etc. Enrico Fermi felt very strongly that *all* scientists should be trained as phenomenologists—men who can apply logical scientific analysis to unfamiliar problems.

Now, in our universities, we tend to be segregated into departments and the types of problems that we solve are greatly restricted. NASA is helping with their Institutional Grants to break down these departmental barriers. Our Theoretical Chemistry Institute is already interdisciplinary and works informally with many departments.

Recently, I helped A. C. Eringen found the Society of Engineering Science to help bring scientists and engineers together. In order to work effectively with problems involving unusual environments and extreme conditions, scientists and engineers must become closely allied or else they acnnot cope with the close coupling between the macroscopic and molecular properties. We believe that theoretical chemistry can play an important role in space science.

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COMMENTS

***Pimentel**, University of California:* In a preceding paper it was mentioned that there is no chemistry division within NASA, but it was also noted that there are many materials problems facing us. Is there conscious effort within NASA to implicate and encourage chemists to participate in these important problems.

***Holloway**, NASA:* This matter of identification of disciplines has been much discussed. The NASA organization is, I think, defensible. We don't have a physics division or a biology division or a mathematics division. There are arguments in favor of such divisions, but in planning the organization in 1958 the solution of operationally identifiable problems was paramount, and I think it is reasonable that in those days NASA should have been organized along those lines. The chart carried such divisions as materials, structures, propulsion, and then the space sciences, lunar and planetary, geophysics and astronomy, and so forth. To find out how much chemistry is being done within the laboratories and under the extramural programs requires, first of all, a definition of chemistry. By definition most of the chemistry, mathematics, physics, and biology can be sorted out and measured by dollars or by man hours. To say that NASA is not doing enough in chemistry may well be true. The resource limitation is common to all our programs, but the lack of a name of a physics division or a chemistry division, I think, is only superficial.

We would probably conclude, if the support given each discipline were ascertained as could fairly easily be done, that in certain fields we are not doing as much as we would like. We look to other agencies for part of this support and we look into other programs within NASA for some of it, although they bear different labels. If good chemistry is buried in propulsion programs and materials programs, I think we deserve credit for the amount that exists whether you can find it by label or not. We don't know any way to label it without restructuring to appear as a national science foundation, which we aren't.

Computer-Oriented Research in the Space-Related Sciences at the University of Maryland

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In March 1963, the National Aeronautics and Space Administration awarded Research Grant NsG–398 to the Computer Science Center of the University of Maryland. This grant is entitled "Computer-Oriented Research in the Space Related Sciences" and is in support of a multidisciplinary research program concerned with the application of modern high-speed digital computers to research projects in a broad spectrum of the space related sciences. In particular, this program is aimed at stimulating and broadening the effective use of computers in the University's space related efforts and at investigating new methods of computer application in these fields.

When a computer is used as part of a research project, the high cost of the necessary equipment, problems of receiving proper programing help, and so forth often overshadow the entire computational effort and overstress the service nature of the computer work. However, more and more research investigators have become aware of the fact that this service aspect should not be the major consideration in the application of computers to their work. Rather, a highly significant and important contribution stems from the fact that the analysis undertaken to make possible the assistance of computers will often stimulate a type of feedback that casts new light on the research problem itself, thereby, in turn, furthering the research effort. At the same time, challenging research problems often arise concerning methods and concepts of computer application in general or, in other words, concerning relevant problems in computer science. The research program therefore aims to stimulate this type of thorough analysis in the computer science aspects of the University's space research projects, thereby making the investigators aware of new possibilities and potentially new approaches to their problems as provided by the computer. In support of this effort a research program has been started on a number of problems in computer science, in order to deepen our knowledge and understanding of the methods and ideas underlying the use of computers in research.

The main responsibility for the research program is carried by the Computer Science Center of the University of Maryland. The Center is an interdisciplinary research department of the University of Maryland, not associated with any college or school within the University. The Center now also offers a number of regular undergraduate University courses in computer science and plans are under way to establish a graduate degree program in this field. In cooperation with the NASA-Goddard Space Flight Center and The Catholic University of America, the Center also conducts a regular seminar and colloquium series on special topics in computer science.

A brief list of principal facts about the Center is given as follows:

Computing equipment

One IBM–7094–I with 16 tape drives
Two IBM–1401 satellites sharing 6 tape drives with the 7094
Associated off-line card handling equipment

Computer use

Current average log-time: 590 hours/month (3½ shifts)
Total number of project numbers: 416
Number of projects under NASA program active during 1964: 95
Current average number of production jobs: 6000/month

Personnel

Professorial Faculty	7	Senior Administrative Personnel	3
Part-time Faculty Consultants	9	Programing Staff	14
Graduate Research Assistants	11	Operating Staff	22
NASA Fellows	3	Secretarial Staff	4

Not counting the graduate assistants and the operational staff, and so forth, there are 33 full- and part-time professional staff members of which 15 hold a doctor's, 8 a master's and 7 a bachelor's degree as highest degree. Of these 33 persons, 18 are presently in some way involved with this research program, representing a full-time equivalent of about 10 people.

In line with the two aims mentioned previously of the overall program, there are two distinct areas of work, namely, research in computer science and computer-oriented research in a number of space related disciplines. A breakdown of the work presently under way in the first area is as follows:

(1) Programing and computing systems
  (a) General programing and monitoring systems development
  (b) Crystallographic structure determination system, X-Ray-65
  (c) Programing system for electrolyte computations
  (d) Special purpose chemical engineering computing system
(2) Computer and information science research
  (a) Nonlinear problems of numerical analysis
  (b) Image processing and pattern recognition
  (c) Consequential languages and procedures
  (d) Information storage and retrieval in depth for a narrow field

For the sake of clarity, computer science research has been subdivided into two subareas, one dealing with programing and computing systems, and the other involving more general research projects in computer science. We might first discuss the programing systems work.

Any effective utilization of modern, complex, large-scale computers depends crucially on the availability of versatile programing and monitoring systems. This is especially true when these computers are to serve a multidisciplinary research program such as the one under discussion, where the proper selection, adaptation, and diversification of highly flexible programing systems are basic to any successful work accomplished under the program. Consequently, one of our first actions was the establishment of a special computer systems group explicitly charged with the selection, implementation, and modification of existing systems as well as the design and programing of new systems. It should be stressed that this is a continuous and never-ending task in view of the constantly changing requirements of the individual research projects using the system.

Figure 1 presents a schematic diagram of our main programing system. Several other separate systems are available on request. Basically, we believe that the research user of the machines should be able to use, whenever possible, the appropriate computer language for his problem. We therefore continue to adapt and incorporate new languages under the system. The hatched areas indicate subsystems which were added to the original IBM–IBSYS monitor by our systems group. Some of them are designed to facilitate use of such highly important languages as IPL–V, OMNITAB, MAD, UMAP, and ALGOL; others represent special developments of multiprecision packages such as MPP and PRECISE; finally, MOIST is a special macrolanguage for flexible input-output and X-Ray-65 is a subsystem which will be discussed subsequently. The MAMOS submonitor is our

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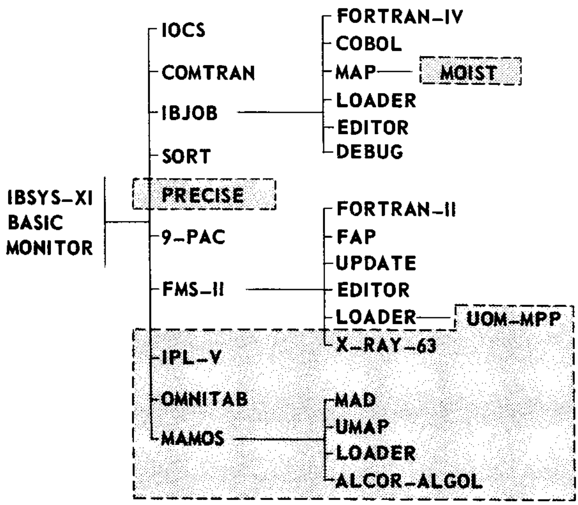

Figure 1.—Schematic diagram of main programing system.

own development, which has proven to be highly flexible and is even now being adapted for use on an IBM–7094–7044 direct couple system at the NASA-Goddard Space Flight Center, and at Yale University.

When a particular research project involves a wide variety of computational aspects, it frequently becomes necessary to combine all these aspects under a special programing system, giving the investigator flexible and ready access to all his programs and providing for automatic data transmission between all of them. There are three such special systems under development at the Center, one concerning crystallographic structure determination, another one dealing with electrolyte computations, and a third involving special-purpose chemical engineering computations. We might discuss one of them, namely, the crystallographic system called X-Ray-65.

The problem of determining the structure of crystals is at present one of great interest to chemists, biologists, and geologists. This research project is directly concerned with the development of methods and corresponding computor programs for the accurate determination of the atomic parameters in crystals from X-ray or neutron diffraction data of solid crystalline material. In the beginning of programing for the solution of crystal structures, it was common practice to write isolated programs for each application. As data gathering techniques improved and became more automated, the need arose to improve and automate the total computational task as well. The programs under development here have accomplished this goal and make up the beginning of a much needed crystallographic computing system.

Table I shows the present extent of the system. The major subroutines perform the calculations necessary to interpret X-ray diffraction patterns and to establish accurate atomic parameters in crystals. Other programs perform systems-link functions and help in the preparation of data for publication.

Figure 2 shows how a data deck is prepared to control the sequence of the different computations desired by the investigator. Various control cards direct the automatic flow of data from one program to the next. The cards with an asterisk on the side represent major program calls. For example, DATRDN calls for the application of Lorentz and polarization corrections and for the encoding of space group information; FC is the structure factor program for all space groups and settings; FOURR is a general three-dimensional Fourier analysis program; DIAGLS, a special and frequently used version of a more general full matrix program, ORFLS, for least-squares analysis; and finally, BONDLA calls for the calculation of bond lengths, angles, interatomic and molecular distances, their estimated errors, and so forth. Among the many possibilities of special data output is a pictorial type output shown in figure 3, which directly shows the crystalline configuration of the substance.

The X-Ray-65 system is used frequently not only by the University's crystallography group but also by a number of other institutions, including the NASA-Huntsville Space Flight Center, the National Bureau of Standards, and many other research organizations and universities.

Let us now discuss the second area of computer science research. As previously indicated, several projects are now under active con-

Table I.—Major Divisions of the X-Ray-65 Systems

Division	Operational	In planning and checkout stage
Systems maintenance and intersystem compatibility	6	--------
Data gathering	4	--------
Cell parameter determination	2	--------
Preliminary data treatment	4	4
Structure solving programs	6	7
Parameter refining programs	4	3
Structure interpretation and presentation	7	5
Service programs	3	6
Systems-function control	13	--------
TOTAL	49	25

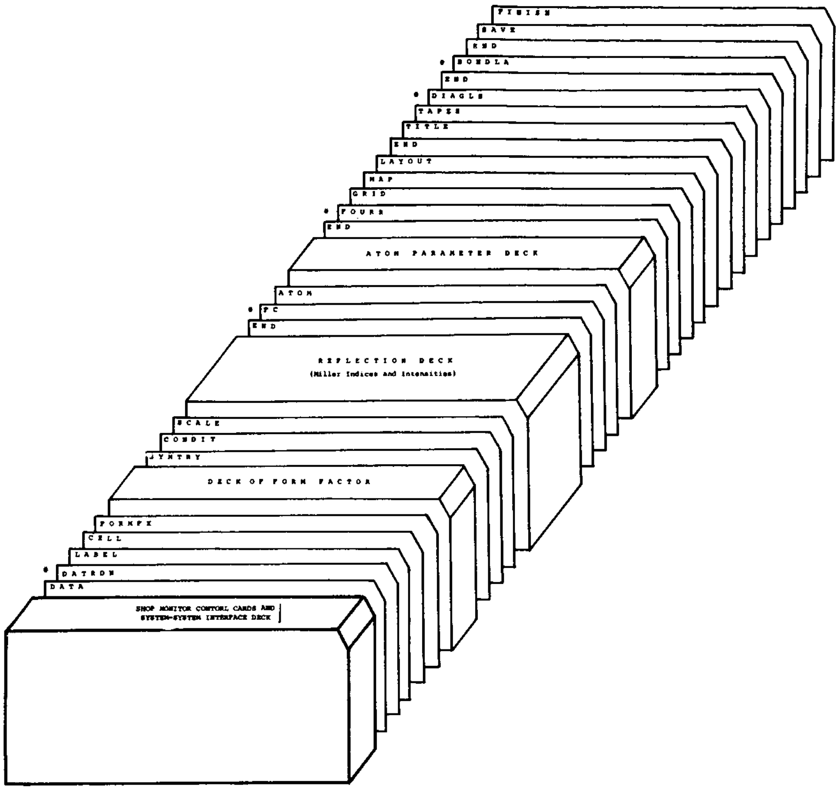

Figure 2.—Example of data deck for the X-Ray-65 system.

sideration; they concern such widely diverse areas as numerical analysis, automatic image processing, mechanical languages, and information storage and retrieval. Let us briefly consider the first two projects.

In numerical analysis we are primarily interested in the numerical solution of nonlinear functional equations. This particularly concerns nonlinear integral and differential equations, and thereby of necessity also nonlinear systems of finitely many equations in finitely many unknowns, as shown in the following numerical solution:

Special equations of interest

Nonlinear integral equations $\int_a^b K(s,t,x(t))\, dt = y\ (s)$

Nonlinear ordinary differential equations
(with suitable initial or boundary conditions)
Nonlinear systems of n equations in n unknowns

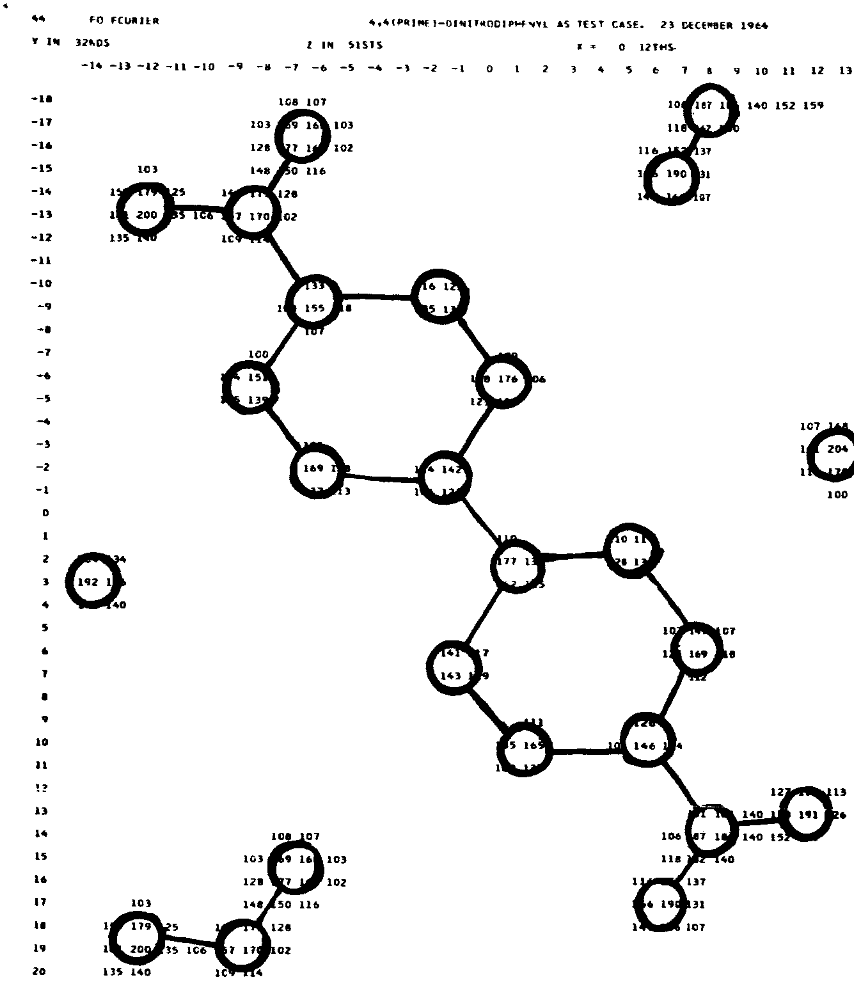

Figure 3.—Pictorial output showing the crystalline configuration of the substance.

General setting

X, Y Banach spaces

$F: X \to Y$ nonlinear mapping from X into Y

Design and experiment with algorithms for solving $\mathbf{F}(x)=0$ For theoretical investigations, all these different cases can be subsumed under the general problem of finding and analyzing algorithms for the determination of solutions of a general operator equation in Banach spaces. There is no scarcity for applications in which such nonlinear problems occur. Some of the specific applications that prompted us in part to begin this particular research investigation are listed as follows:

Two-point boundary value problems, e.g., trajectory problems
Control problems
Flow problems
Minimization problems

To some extent we became aware of the trajectory and control problems as a result of discussions with colleagues at the NASA-Goddard Space Flight Center.

Among the many different methods that can be applied to the nonlinear problems under consideration, we are concerning ourselves particularly with the following:

Local methods

Generalized Newton method
Generalized secant method
Methods of Gauss-Seidel and
Jacobi-type for nonlinear systems
General implicit iterations

Global algorithms

Use of perturbation techniques
Davidenko's method
Use of imbedding techniques

The study of Newton's method for general operator equations in Banach spaces originated with the Russian mathematician L. V. Kantorovich. Its application to such specific problems as mentioned earlier presents a variety of challenging research questions which are attracting growing attention in this country. The generalized secant methods are even less understood than Newton's method and their application—though computationally desirable—present even more serious problems. The Gauss-Seidel and Jacobi-type iterations for nonlinear systems of equations appear to carry a great deal of promise for effective computational work, and have only recently come to be considered for use on specific applications. The same is true for the so-called implicit iterations which contain all previously mentioned methods are even less understood than Newton's method and their of a suitable initial approximation which in turn must often be already close to the desired solution. Global methods are therefore highly necessary to overcome this restrictive condition. Our three areas of work on global methods are also given in the preceding list.

The particular problems now under active study are:

Newton's method

Conditions for monotonic convergence and their importance

Influence of different approaches to the discretization problem
Relations to gradient-type methods

Gauss-Seidel and Jacobi-type iterations

Theoretical and experimental comparison of asymptotic rates of convergence
Global convergence

Secant methods

Theoretical and experimental convergence
Sufficient conditions for convergence

It should be stressed that we are working on parallel tracks with the theoretical investigation of all methods and their computational evaluation for specific applications. In addition, we hope to develop versatile programs in a general algorithmic language for all these methods. A number of very promising results have already been obtained, even though this particular project has only been under way for about 6 months.

The earlier mentioned project on Image Processing and Automatic Pattern Recognition concerns the following areas of research:

Image processing research

Discrimination of connected regions
Discrimination of "solid" from "broken" regions
Measures of shape "skeleton", "capacity", "frame"
Computer-generated patterns for vision research

Applications

Cloud pattern analysis
Contour map processing

Research in digital image processing has tended to be concentrated in two areas: "local" processing of images as two-dimensional data arrays, usually for the purpose of simplifying the image, and processing of images which consist of discrete, well-defined parts in given topological and metric relationships. In the area of the discrimination of connected regions of an image, a general computer program called RAMP has been developed and written, which constitutes an important step toward bridging the gap between the mentioned two "types" of image processing research. RAMP identifies and computes the areas of connected regions—defined by those image points which have a given range of density values—on a digitized image. Figure 4 shows a line drawing done by hand from a cloud-cover picture, and Figure 5 shows the output of RAMP from the actual digitized picture. Two other image processing techniques were developed and programed representing alternative approaches to the problem of identifying regions on an image that are free of detail and

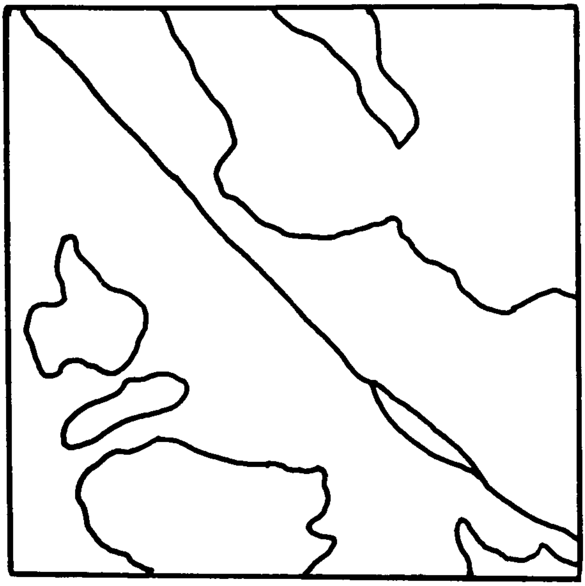

Figure 4.—Line drawing done by hand from a cloud-cover picture.

have regular boundaries. These programs are called SORD-(which stands for "Solid Region Delineator") -1 and -2. All three programs have been experimentally applied to the problem of analyzing the cloud-cover pictures and maps obtained from the TIROS satellite.

A variety of approaches to the automatic recognition of shapes has been proposed. Under this project, three novel tools for shape description and analysis are being investigated and developed further; namely, the so-called methods of (1) shape skeletons, (2) shape capacity, and (3) shape frames. In each case, versatile computer programs were written and are now being applied to a variety of special problems. The shape skeleton method is particularly interesting; it consists in the "propagation" of the boundary of the shape over the plane in the manner of a wave disturbance. Figure 6 shows a simple line drawing representing a particular shape. Figure 7 gives the actual computer printout of the "propagation" process. Points through which the wave front has passed become "refractory," that is, resistant to further wave passage. Under these conditions the wave front which propagates inward will intersect itself and eventually cancel itself out. The locus of self-intersections of the propagating waves provides a highly useful "skeletal" representation of the given shape and can be used in succeeding programs to provide detailed information about the shape.

A totally different area of research under this project concerns the problem of visual discrimination of texture by human observers. The appearance of "uniform texture," characteristics of probabilisti-

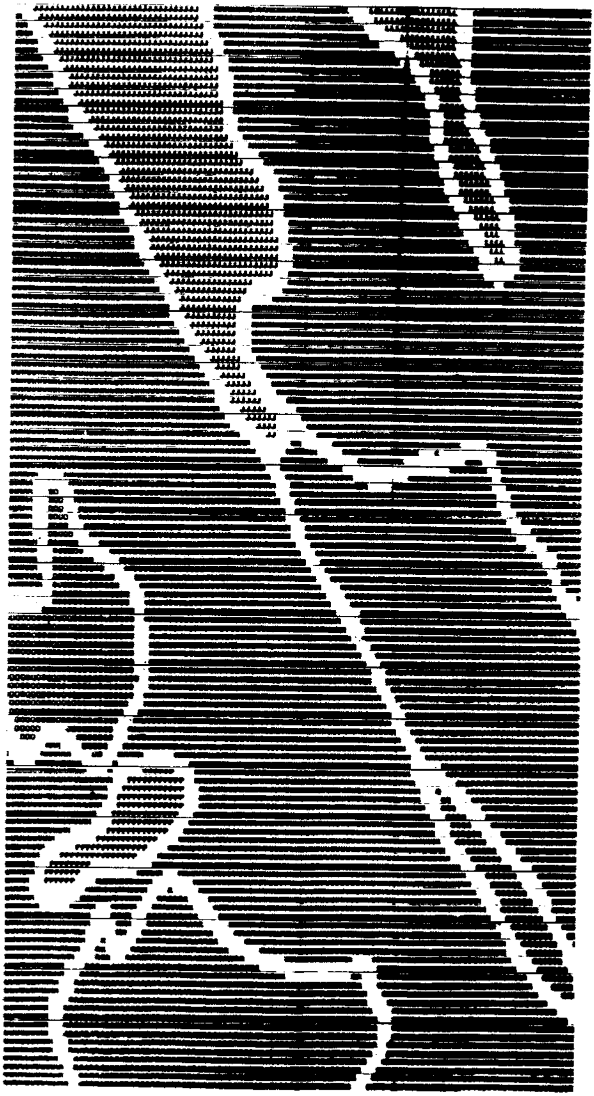

Figure 5.—Output of RAMP from the actual digitized picture.

cally-generated visual stimuli suggests that the brain may measure or estimate statistical parameters of such stimuli, as, for example, luminance values and luminance gradients, periodicities of these values, and so forth. In searching for statistical, stimulus-analysis and stimulus-processing mechanisms which may be involved in visual texture perception, it is desirable to study situations involving as few relevant stimulus dimensions as possible. For example, consideration can be restricted to stimuli which are either "black" or "white" at every

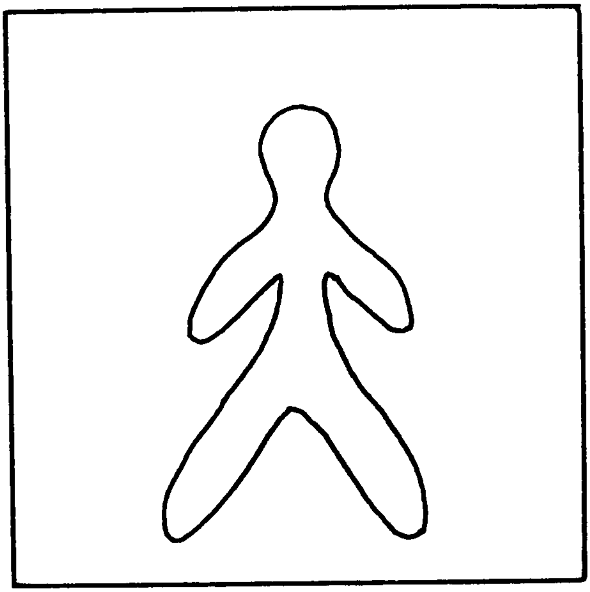

Figure 6.—Simple line drawing representing a particular shape.

point. Another, more drastic, restriction to stimuli which are "one-dimensional" can be used to minimize the significance of form and pattern variables, alternatively. A versatile computer program for generating patterns constrained in one direction and random in the other has been developed. Figure 8 presents an output pattern from this program. These patterns are printed out by overstriking up to six printer characters to form the solid black cells. Subjects are shown these patterns and asked to locate boundaries. Experiments of this type have studied boundary location performance with respect to the very basic mean luminance variable. In other experiments now in progress, mean luminance has been equalized and the variables under study are the frequency distribution of black and white "run lengths" or "patch sizes".

As discussed previously, the entire research program consists of two parts—computer science research, and research into the computational aspects of particular space-related problems. Table II shows the extent of the second part of the program now in progress. Only a very cursory glance at this fairly extensive, interdisciplinary, research undertaking is feasible since every one of these projects would require considerable description of the physical background and the computational problems involved.

It may be mentioned that the work listed under Molecular Physics concerns primarily kinetic theory and spectroscopic studies on the fundamental properties of molecules. The heading "Physics and

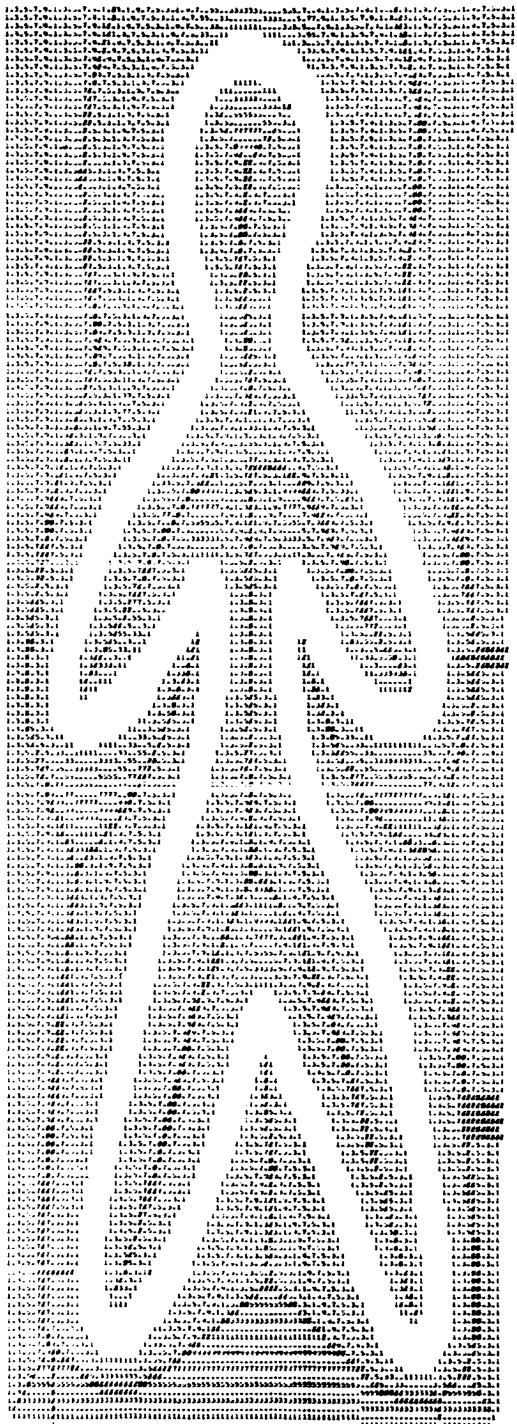

Figure 7.—Actual computer printout of the "propagation" process.

Figure 8.—An output pattern from a computer program developed for generating patterns constrained in one direction and random in the other.

Engineering of Fluids" includes computational work in plasma physics; in particular as it applies to phenomena in the ionosphere and in space, and so forth and it also includes problems of magnetohydrodynamics and the flow of gases at high temperatures. The work in astronomy is mainly concerned with radio astronomical observations and galactic and stellar models, while problems in psychology cover such studies as psychomotoric testing of pilots.

Rather than simply enumerating the entire list of topics now under active investigation, two particular projects may be singled out. Their choice was dictated largely by the ease with which it is possible to discuss the physical background, rather than for any other reason.

Table II.—Computer-Oriented Research in Space Related Fields

Field	Department represented	Number of projects
Molecular physics	Chemistry, inst. for molecular physics	7
Nuclear physics and nuclear engineering.	Physics, chemical engineering	16
Particle and field physics.	Physics	7
Physics and engineering of fluid.	Inst. for molecular physics, inst. for fluid dynamics, physics, chemical engineering, aeronautical engineering.	18
Mechanical and elec. engineering.	Mechanical engineering, electrical engineering.	7
Other disciplines	Astronomy, physics, mathematics, psychology, electrical engineering.	8

The first of these two projects concerns an in situ probe system for the measurement of ionospheric parameters. For many years now, the ionosphere has been the subject of experimental investigation. The advent of rocket sounding vehicles and satellites has considerably intensified this activity, and at the same time has shifted the experimental emphasis to in situ probes which are, of course, potentially capable of more refined measurements of various ionospheric parameters. For several years, the Center for Atmospheric and Space Physics of the University of Maryland has been conducting a research program aimed at developing a complete in situ probe system in particular. This system consists of (1) thermal equalization probes capable of independently measuring vehicle potential, (2) a pulse probe to measure electron concentration and energy distribution and (3) a Langmuir probe to supply information on positive ion and electron temperatures. This system has been completely designed and tested both in the laboratory as well as in preliminary rocket flight tests. A very substantial part of this design and testing work concerned the development of adequate computational approaches to the calculation of instrument behavior and characteristics. Figure 9 shows a picture of one of the thermal equalization probes. It represents essentially a unipotential cathode which, when heated, begins to emit electrons thermionically. In general, the unheated probe in ionospheric plasma assumes a negative potential. When the probe is heated, the outgoing electron flux partially balances the incoming flux of electrons from the plasma, causing a decrease in the probe potential. Figure 10 shows computed curves of potential versus

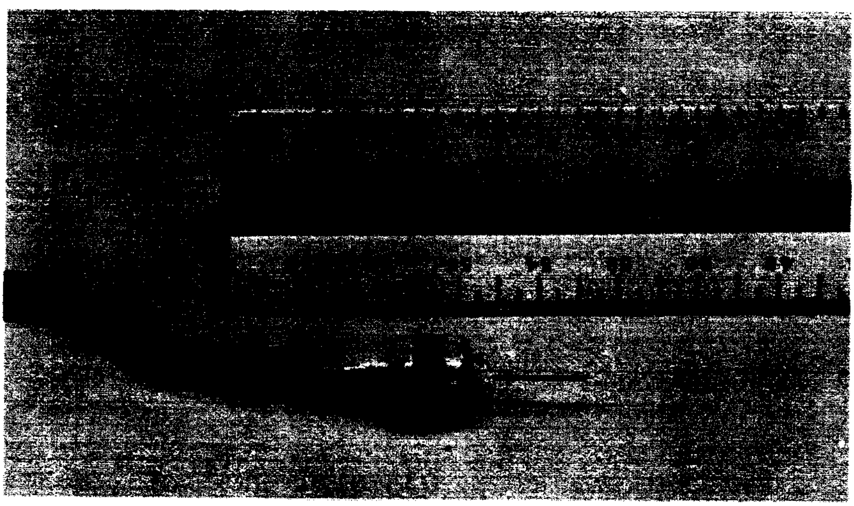

Figure 9.—Thermal equalization probe.

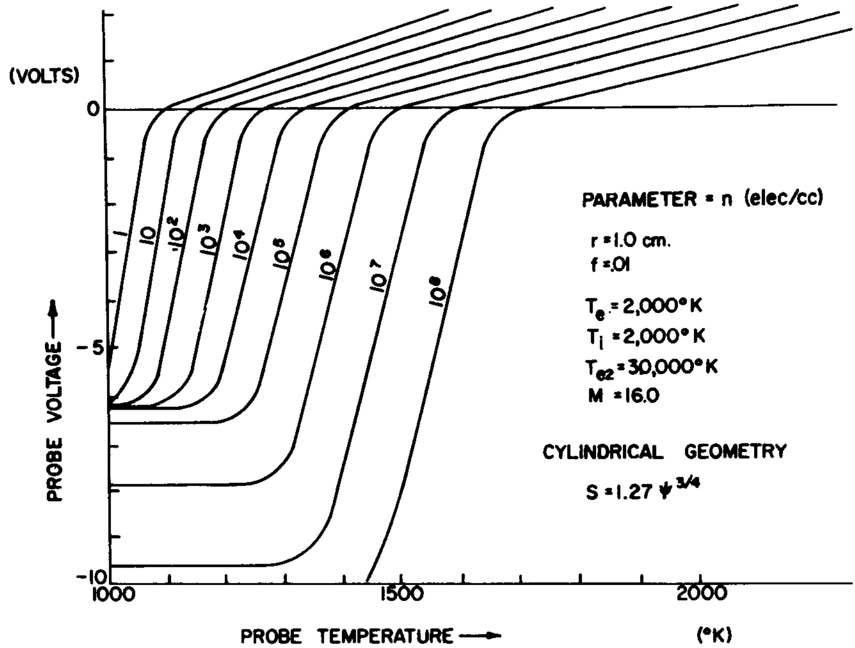

Figure 10.—Computed potential curves plotted against temperature for thermal equalization probe.

temperature for such a probe. All these curves display a very sharp readily identifiable knee at the plasma potential. A probe whose temperature is set to operate a little above the knee will therefore provide a continuous measure of the vehicle plasma potential. Figure 11 gives actual measurements in flight and shows that the computational results agree very satisfactorily with actual measurements.

As a last project we might mention a very extensive experimental and theoretical research study concerning rotating laboratory models which simulate the general circulation of the atmosphere. Figure 12 is a schematic diagram of the experimental vehicle, a large rotating tank. Fluid is pumped out of the center area and flows back into the tank on its outside rim and, more specifically, into the boundary layer on the bottom of the tank. Dye crystals are dropped into the tank in the rim area to trace the circulation. Figures 13 and 14 give a typical picture of this type, taken from above the tank. A very important part of this research program concerns the numerical prediction of such circulations, involving the numerical solution of nonlinear partial differential equations under fairly general boundary conditions. These circulations are in many respects similar to the general circulation of the atmosphere, and the uses and limitations of numerical

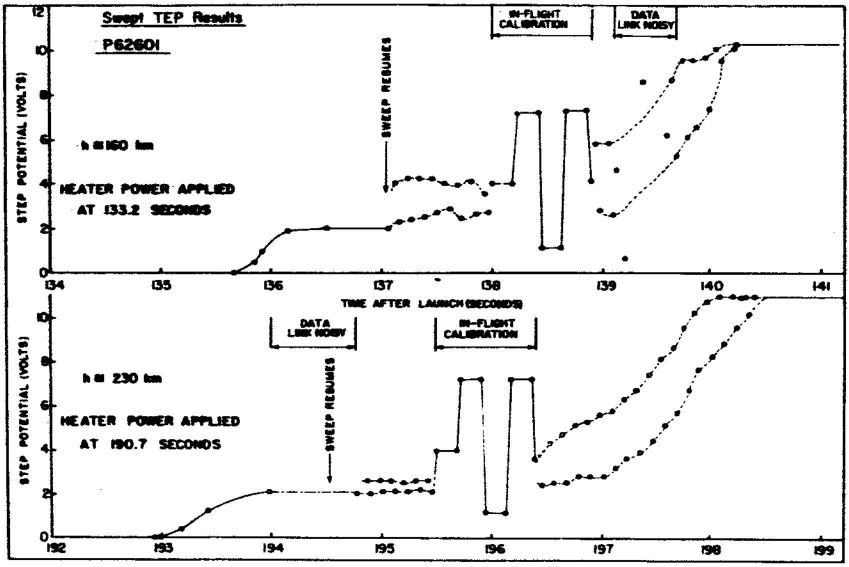

Figure 11.—Actual in-flight measurements showing satisfactory agreement between computational results and actual measurements.

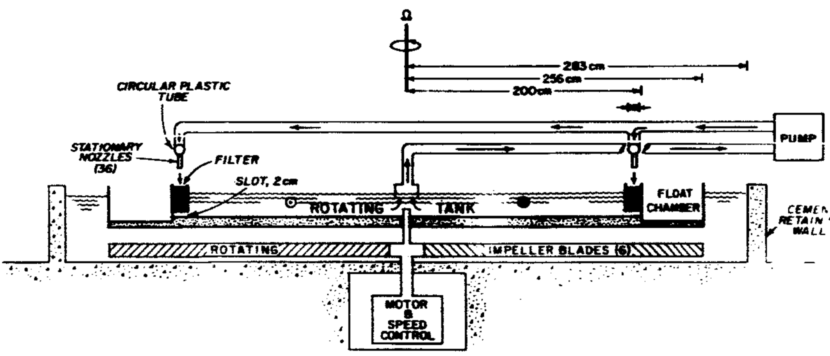

Figure 12.—Schematic diagram of the 4-meter rotating tank.

methods for the prediction of weather can therefore be tested in these rotating fluid "models." Initial numerical prediction work concerns simple models which permit the parameterization of the viscous boundary layer at the bottom. Figure 15 gives the output from such computations for the perturbation stream function in a cross section of the tank, about half a radius away from the center. The printout has been arranged in such a way that it is possible to connect equal values in different columns and obtain a graph of the perturbation. The perturbation shows the cross section of vortex rolls which appear in the particular region. The experimental and the corresponding

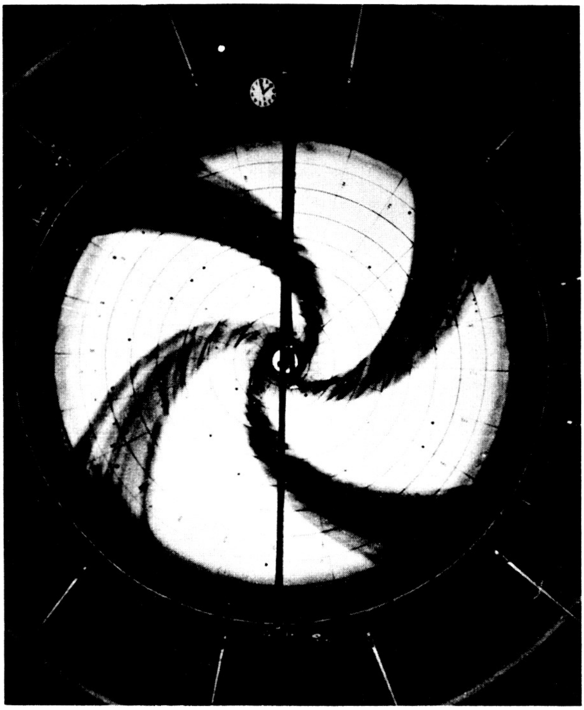

Figure 13.—Typical circulation patterns obtained with the 4-meter rotating tank. Spiral arms are dye used to trace flow from periphery to center.

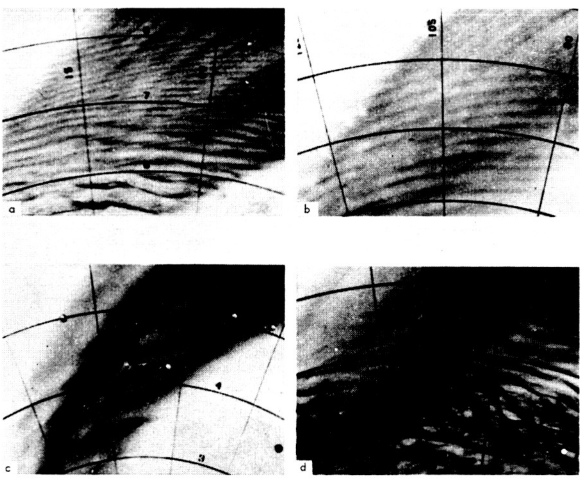

Figure 14.—Detail of figure 13 showing striation.

numerical model is being complicated in successive stages in order gradually to approach the situation in the atmosphere. For example, as a next step, vertical thermal gradients are now being introduced. Clearly then, the ability to predict laboratory circulations with a given numerical prediction technique will indicate the feasi-

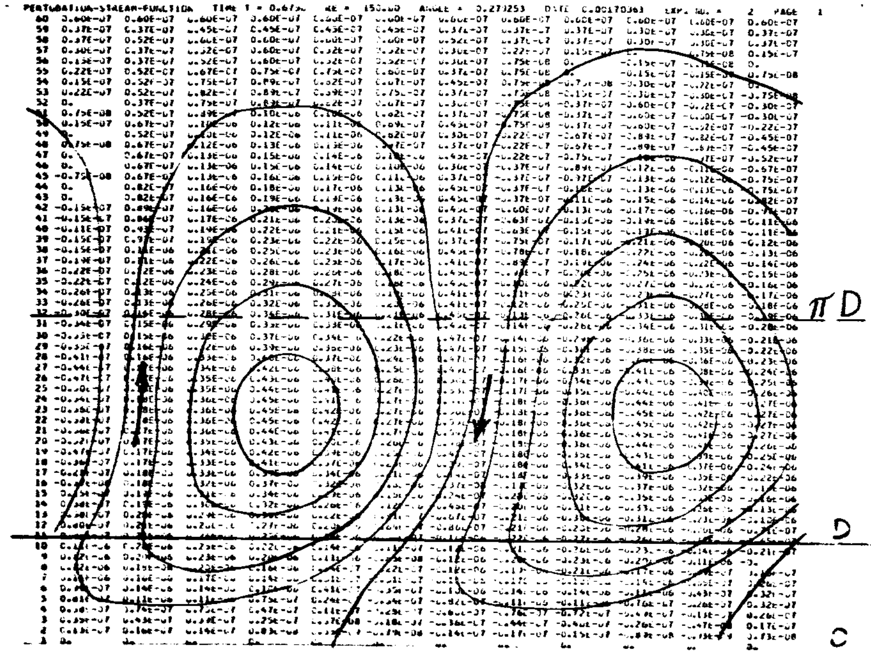

Figure 15.—Perturbation stream function. *Re* =150; amp. =0.45×10⁻⁴.

bility of using the same technique for predictions of similar circulations in the atmosphere.

As was stressed several times, it is not possible to give more than a very cursory picture of the work performed under the NASA-Research Grant NsG–398 at the University of Maryland. More detailed descriptions can be found in the various reports and publications that have already originated from the work. (See "Bibliography.") In our opinion, the results show very clearly the extreme importance of bringing together computer scientists and research investigators of various space-related problems, thereby stimulating and broadening the work of both.

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COMMENTS

Hancock, Purdue: What is the extent of your computer science program? Also, in listing the projects concerning the various other departments, were NASA funds used for support of all these programs or were these primarily obtained from the departments themselves?

Rheinboldt: As yet, we do not have a degree granting program, although there is a plan for establishing one as soon as it can be done. With regard to the other departments, we are providing the computer aid to particular projects, but in most cases they may have some loan support or they might just be starting. For example, the ionospheric probe had other support for the experimental work. The computer science projects are more largely supported directly by NASA under this grant.

Kidd, Princeton University: You indicated that there are approximately 6000 jobs per month and 63 projects. To follow the previous question, is there an accounting procedure and are there individual charges, or is this work open? Also, is there a scheduling problem?

Rheinboldt: We are, under the monitoring system keeping track of what we are doing on the machine. We charge the projects if there is indeed some budgeted fund for computer time; otherwise it is supported by state funds. These NASA projects are half supported by state funds and half by NASA grant. We are essentially making a charge that is in part covered by the state and part by this grant.

At this time we have only a mild and minor scheduling problem, but we will be having more and more problems. We have a variety of schemes for handling them.

Sells, Texas Christian University: Do you have any provision in your program for giving aid or support to work in related areas at other institutions?

Rheinboldt: No, there is no fund for that available; however, we have been helping,to some extent, Catholic University on some projects that were a little too large for their computer. We gave some aid at the University of Delaware on some projects, too, but this was on a private individual basis.

Zenor, University of Missouri: You outlined more or less the standard techniques of computer science. Does your grant allow you to move away from standard techniques to develop techniques which would be of interest to people who are computer science people, or are you required to work routine problems for the actual solution of engineering problems?

Rheinboldt: One group of projects is intended to develop methods that are of interest to the computer scientists. We are looking at problems at this time that are in some way space related, but this is due to the fact that the University of Maryland has a fairly active space-related research effort and this provides the stimulus. However, we are in no way required to work on a specific application problem. We hope that methods we develop will be of use in some way.

Summerfield, Princeton University: I would like to make a comment in a somewhat broader context. This paper makes a very impressive case for the kind of support that a computer group can give to the problem-solving activities of the research projects around the University of Maryland; I am sure that this is true with other universities. I am concerned, however, about the developments that seem to take place in the educational sense when the computer center becomes established at a university. When a computer center becomes established all eyes are focused on it; it attracts the faculty, the research people, and the students. There tends to be a draining away of energies from what should be a proper concern, namely, the larger area of mathematical education. There is a tremendous need for the development of mathematical education. It might be called applied mathematics, or mathematical analysis, or identified as the study of partial differential equations, of integral methods, of various sophisticated approximation methods—tools that will resolve intricate problems.

However, students have learned to turn to the computer. The student of today has access to funds. He finds that he can work out the system of equations on the computer and I do not deny that many things can be learned by seeing these equations displayed in their full form. But the student is deprived of the intellectual exercise of thinking mathematically as a physicist or thinking as a physicist mathematically. He has somehow lost the ability to relate these intricate equations, these intricate mathematical problems, to the physics of the problem because it is so easy to use the computer. This has happened not only to the student in his individual research, but it seems to have happened in the way we educate students. Is NASA concerned with the larger problem of encouraging mathematical analysis on the campus? If you try to find course work on campuses or the kind of education that we would like to see in the field of mathematical analysis under any department, it is almost nonexistent.

Rheinboldt: I agree wholeheartedly with your viewpoint. Something has to be done. It is quite clear that a computer science center, as such, cannot provide such an educational program. I feel that the educational aspects have to be developed in disciplinary programs and in special departments of some sort. How it is done politically in a university is a question to be answered by the university. I have no answer as to how it can be done.

Filling the Void

Shirley A. Johnson, Jr.

DIRECTOR, DENVER RESEARCH INSTITUTE

UNIVERSITY OF DENVER

THE PRICE TAG ON THE HEAD OF EVERY PH. D. produced in the physical and engineering sciences is currently about $125 000 (refs. 1 and 2). This is the money, in the form of grants, contracts, and fellowships that administrators in higher education must find, scrape up, beg, and borrow from government agencies, state legislators, foundations, industry, etc. Most of this money as it comes to us is earmarked, pegged, and restricted to specific investigations and pre-negotiated programs, to be conducted by Professor X and Student Y, according to Client Z's ground rules. With such fragmented building blocks an attempt is being made to build graduate programs of excellence, but not without severely induced stresses and glaring gaps in the framework. There are, however, bright spots on the horizon with new, emerging concepts of Federal support to higher education, pioneered to no small extent by the National Aeronautics and Space Administration. It is the purpose of this paper to focus on one aspect of NASA's Institutional Grant Program and to show how it is filling the void at the University of Denver.

On October 1, 1963, the University of Denver initiated a significant, new program of research in space-related sciences, under NASA research grant NsG–518. A total of $200 000 was vested under this grant, which resulted in a funding level of $100 000 for the first year and step-funding for 2 successive years. After the first year of operation, the grant was supplemented by an additional $150 000, which increased the level of funding for the second year to $125 000 and provided step-funding for the third and fourth years of the program. An investigation of the depth of this program indicates why Denver is convinced that this $125 000-per-year grant is having a greater impact than most other existing X–Y–Z grants and contracts with much larger price tags.

First, it is important to consider the University of Denver, and in particular its physical and engineering science activities, in its proper perspective. The University, a private, nontax-supported institution, is at an eventful point in its 101-year history. Since World War II, the University has taken major strides in greatly expanding its graduate academic programs. The student body numbers 7100 of whom 2300 are graduate students. During the last 4 years, doctoral programs have been initiated in chemistry, chemical engineering, electrical engineering, metallurgy, and physics. Doctoral programs in mathematics and theoretical and applied mechanics are scheduled for the immediate future. In these disciplines, there are 239 candidates for advanced degrees, of whom 63 are doctoral candidates. It is anticipated that these numbers will double in the next 4 years.

Accompanying these developing graduate studies, of course, has been a rapid augmentation of faculty and supporting research staff. One index of this augmentation is that sponsored research from grants and contracts has increased from a level of $2 million per year in 1960 to $6 million per year in 1965. Now, how can Denver truthfully say that one NASA grant in the amount of $125,000 per year is producing a major impact to an organization conducting $6 million per year in sponsored research? It does and the reasons are given subsequently.

Several years ago an in-depth, soul-searching analysis was undertaken of the programs, the method of operation, the sources of funding, and how these funds could be deployed. A number of problem areas were brought into focus that included the perennial headaches of equipment build up and the acquisition of bricks and mortar. But the most acute problem area identified, which came as somewhat of a surprise, related to the professional development of the junior staff, the assistant professors, and the research associates. It was this body of young men, newly launched in the academic world, numbering approximately 40 percent of the total faculty, on which the future of the University would eventually depend.

More than once, an Assistant Professor at Denver blithely and with naive confidence, bolstered by his new Ph. D. sheepskin, his name included on a refereed paper, stepped into the public market place of the givers and the takers of the research dollar, only to be slapped down by a form letter turning down his proposed research.

After the second or third unsuccessful attempt, this disillusioned young man would return to the blackboard, resigned to a life of classroom instruction, rationalizing, that there is an unhealthy emphasis on research anyway. The unfortunate fact of life is that this young man, unless something can be done about it, will remain stagnant as the scientific world around him rushes on and, within a period as short as 3 years, can be completely sterile as a researcher. Are those in graduate education doing their job in not better assisting this young man to develop into full professional maturity? Not all faculty are destined to do original, creative research but those who are so gifted must not be lost because of the vagaries of the system.

In the analysis of this situation several years ago, the question was raised, what is being done? The answers were standard: teaching loads were reduced (as funds permitted) for select members of the junior staff, an occasional trip to a national society meeting was scheduled, talks on professional development were given, unofficially utilizing their services on research in progress, etc.

One important ingredient was too frequently missing. These young fellows did not need pampering; in fact, on the contrary, they needed to compete with senior, established investigators, to argue and defend their premises, to accept expert tutelage on the difficulties that may be ahead, to sever, if necessary, the bond confining their scope of vision to permutations only of their doctoral dissertation, and to stand up with conviction and say, "These are my ideas."

A second important ingredient was missing. The general unavailability both locally and nationally, of limited venture funds to gamble on these young, unproven investigators. With these thoughts in mind Denver decided to do something. After contacting several institutions NASA finally granted us an impedance match.

In the cold, impersonal terms of the legal instrument establishing the grant, the primary purpose of this program is to broaden research in the space-related sciences at the University of Denver by identifying and supporting the less-established but promising young investigator, as well as to foster unusual and creative thought at all levels. The program functions as follows: Policy and administrative action is taken by a newly constituted entity, the University NASA Awards Committee. Membership on the committee includes the deans of the Graduate College, the College of Arts and Sciences, the College of Engineering, three faculty members at large, and the director of the Research Institute as chairman. Applications by faculty for support under this grant program must contain the information specified in a widely distributed in-house document, "Guidelines for Submission of Proposals."

If the chairman of the Awards Committee deems that an application is in consonance with the intent of the program, he constitutes a three-man Ad Hoc Review Committee, consisting of senior scientists and engineers best qualified to render technical judgement. The committee is composed of a faculty member, selected from a department different from that of the grant applicant, and normally two men from sister institutions or regional research laboratories. Also at this time an information copy of the proposal is sent to NASA. If the chairman of the Awards Committee deems that the application is not in compliance with the spirit of the grant, the application is sent directly to the entire Awards Committee for a policy determination.

The Ad Hoc Review Committee conducts a critical but constructive review of both the written and oral presentations by the proposed investigator and makes an evaluation according to the following criteria:

(1) Originality of the investigation
(2) Technical soundness of the study
(3) Extent of investigator's knowledge of the field
(4) Probability of completing the research within the time and funds requested.
(5) Potential contribution to space-related science and technology

On written recommendations by the Ad Hoc Review Committee, the University NASA Awards Committee makes the final determination of whether an investigation is to be funded, and if so, in what amount.

Twenty-nine formal requests for funding under this grant have been received. Of these, 19 investigations have been supported in the total amount of $164 000; four requests totaling $53 000 are under final review, and six have been withdrawn or rejected. The maximum funding to date on any one study has been $13 200, the minimum has been $1500, with an average funding of approximately $9000. Of the 19 investigations supported, 15 were granted to junior staff functioning for the first time as a principal investigator. Of the studies supported, three have been in physics, two in chemistry, four in applied and theoretical mechanics, two in electronics, three in physical metallurgy, two in chemical engineering, and one each in mathematics, psychology, and zoology. The key to the successful operation of such a grant depends on the rigor of the review accorded each grant applicant.

In constituting an Ad Hoc Review Committee, some 26 to date, the most qualified experts in the region were selected. Of the 78 men asked to so serve, not one has declined; in fact, they have welcomed the opportunity.

Considering that 80 percent of the grant applicants to date were making their first formal request for such support, the reviewers loomed formidable and foreboding. As a matter of fact they were, because the reviewers took their assignment seriously. Each received a copy of the written proposal approximately 10 days before the scheduled review session. One reviewer spent an entire day in the library checking each reference in the bibliography. But the real test comes with the face-to-face review, where the premises and theories are searched and probed, where the applicant's knowledge of other investigations in the field is ascertained, and where ramifications to the proposed research may be jointly developed as the concerted thinking of the applicant and the reviewers comes to bear on the problem.

The written recommendations from the senior reviewers were tempered at times with an element of understanding. This does not mean that the reviewers were lenient. More than one-half of those requesting consideration had to redraft and resubmit their proposals, and at least five were so adversely criticized that they were beyond salvage. Frankly, some of the proposals (at least in the first submission) were astoundingly superficial—even when the individual was known to be technically well grounded. Some proposals went to the other extreme and proposed a monmentous undertaking, years of research through uncharted waters—all for $12 000.

If nothing else was achieved under this grant, the experience that these young fellows obtained in learning what constitutes a soundly conceived and defended research investigation should justify the entire program, for most of them have emerged from this process much better prepared to develop into fuller professional stature.

It is quite apparent that this grant has stimulated the staff to explore the interrelation of their research with the broadening horizons confronting space science and technology. The direct and rapid review possible under this grant has encouraged senior investigators to pursue new and interesting concepts with a freedom and speed not achievable heretofore. A nonanticipated major fringe benefit has accrued because a number of the members of the Ad Hoc Review Committees have developed a personal interest in the newly launched research and maintain continuing contact with the investigator.

Seventeen graduate students are participating directly on these studies, making a total of 39 students receiving stipends from NASA grants and contracts. There are active research grants and contracts and training grants from NASA totaling $1¼ million.

There are also other voids being identified in our total space-related research program, and it is anticipated that some of the grant funds be committed on a basis calculated to bring additional strength to an already strong discipline. As an example, appointments may be extended to one or more visiting research scholars for a summer or for the academic year in the area of solid state sciences, a discipline which is developing rapidly on this campus.

Because this Institutional Grant has been in existence only 17 months and only one of the 19 investigations supported to date has been completed, an attempt has not been made to identify and report on specific research accomplishments. The following reports were obtained from the investigators contacted: A paper was being submitted to the West Coast Conference on Applied Mechanics in Los Angeles scheduled for August 1965. In early September 1965 a paper is scheduled for presentation in Budapest at the International Symposium on Shell Structures on "The Matrix and Computer Solution of Cylindrical Arbitrary Shapes." The investigator has just submitted a proposal to NASA on "Analysis of Shells of Arbitrary Shape Utilizing Finite Triangular Shell Elements." A manuscript is in preparation for submission to a refereed journal on "Thermodynamics of Praseodymium-Neodymium Solid Solutions." A proposal was recently submitted to the National Science Foundation asking for continuation of research initiated under this grant. A paper on "Potential Energy Surface of BeH_2" has been accepted for the Alberta Symposium of Quantum Chemistry to be held at the University of Alberta in August 1965. A paper on "Prediction of Pile Action by a Computer Method," was presented in Mexico City at the Conference on Deep Foundations in December 1964. Another paper was submitted to the Engineering Mechanics Division of ASCE on "Deformation Equations for Westergaard Soils." A paper was presented on "The Traveling Reservoir Light Gas Gun," to the American Range Association Meeting in the spring of 1964 and, an updated version was presented on the same subject to the Seventh Hypervelocity Impact Symposium in November 1964. These investigators also received a $28 000 contract to continue research on the concept relating to the hypervelocity augmentation proved out under this grant.

In December 1964 a paper on surface spikes was presented at the Midwest Solid State Conference. The same researcher has a manuscript for submission to the *Journal of Applied Physics* on surface spikes, as well as a letter to the editor of the same journal on convex-concave spiral growths. A proposal for "A Study of the Surface Physics and the Defect State of Layered-Structure Crystals" has been submitted to NASA and other agencies.

Another paper is in preparation for submission to the *Journal of Geophysical Research* entitled "Spectral Dependence of Lunar Emissivity," as well as a proposal in draft to NASA for expansion and continuation of this research.

In summary, the faculty and adminstration of the University of Denver strongly agree that the Institutional Grant is having a major impact on our campus. The breadth of understanding evidenced by NASA in making such a program possible is deeply respected. There is no better example of a sound relation between a Government agency and a university where the objectives and principles of both are equitably sustained.

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A Case History of a Developing Research Program

Irving E. Dayton

HEAD, PHYSICS DEPARTMENT

MONTANA STATE COLLEGE

SINCE MONTANA STATE COLLEGE is not as well known as some of the larger institutions, perhaps it would be well to describe it briefly. Montana State College is located in Bozeman, 60 miles north of Yellowstone National Park. The college is the land grant institution in Montana, the science and engineering center of the state university system. At the present time there are 14 active Ph. D. programs on campus and an enrollment of about 5200 students. Our Ph. D. program in physics is the only such program in Montana or any of the four adjoining states.

Several years ago when we were first starting to think about a graduate research program in physics, we deliberately tried to identify research areas that would be fruitful to pursue. A number of criteria came to mind. One was that we wanted to be working in areas that could be thought of as in the mainstream of contemporary physics. Another was that these should be areas where we could realistically hope to get the kind of facilities and support to be able to do absolutely first-class work. Still another was that we wanted to be in areas that would support other research programs on the campus, and which would, in turn, be supported by them. One of the good features of a modest-size campus is that you can talk to a person in another department without setting up an administrative structure just for the purpose. All these considerations led us to point our efforts toward atomic and molecular physics, solid state physics, and astrophysics.

About the time our activities were getting underway, 2½ years ago, we attended, in force, the NASA-University Conference in Chicago. We talked with some of the NASA staff and found them sympathetic to our position. We explained that we had considerable potential at

Montana State and that what we needed to realize this potential was, in effect, "seed money." The staff of NASA's Office of Grants and Research Contracts has a realistic and sympathetic approach toward the problem of the emerging institutions, those that are not extremely firmly established. It turned out that our interests and NASA's interests actually coincided rather closely. There is great need for additional work in solid state physics to back up materials science development and certainly more work is needed in the areas of molecular physics.

We started out in this general direction. At the present time our research efforts in solid state physics are distributed in a series of programs in electron paramagnetic resonance, nuclear magnetic resonance, low temperature physics, and photoemissive studies of band structures of solids. These tie in nicely with work in magnetic materials and solid state devices in electrical engineering and with solid state chemistry and X-ray crystallography in the chemistry department.

In the atomic and molecular area we have some work going on in electron and ion impact and also measurements starting on oscillator strengths and lifetimes—lifetimes for atomic and we hope eventually, molecular transitions. We have a theoretical astrophysicist in the department, and one of the interesting things has been to see how our new course in astrophysics has attracted student interest. We have sent a number of students to the summer institute at Columbia and a number on to graduate school in astrophysics or space physics, depending on the label given it at the particular institution.

Our intent and our mode of operation has been to use the support from NASA as seed money. I think our basic philosophy is very similar to that outlined by Mr. Johnson in the preceding paper. We have a young faculty and we need a preliminary boost to get started before mounting a full scale proposal. This approach has, in the short time this grant has been in operation, been extremely successful. We have also had two major grants funded by agencies other than NASA. This program is giving the younger staff members a chance to develop, to initiate projects, to try out new ideas so that they are not chained to a continuation of their thesis projects.

At this point, we feel that we do have a viable graduate and research program in the physics department; we are now moving into the second step of trying to interest other departments on campus to use this same approach to develop work of interest to us and to NASA. The renewal proposal recently submitted listed, among other projects, studies of the upper atmosphere and meteor phenomenon by personnel of the electrical engineering department. They have had a long-standing program in communications and systems work and have been very active in the meteor burst communication field. They believe that they can use these same techniques to study the meteors themselves and to study phenomena in the upper atmosphere. A second program in electrical engineering has to do with the development of microwave frequency synthesizers.

In botany and bacteriology we have a very interesting example of the interdisciplinary type of program—in this case some work on wheat rust growing out of agriculture supported research. The wheat rust appears to be responsive to geophysical stimuli of various sorts; what the investigator would like is to make enough preliminary measurements to isolate the type of stimuli responsible. Similar phenomena are being encountered in a research study in hydrobiology in the Madison River Valley.

Two of our chemists have work which they feel is quite relevant to this general area, one in radiation chemistry involving hydrocarbons, such as are known to be available in space, and another involving oxygen-retaining compounds, which also have considerable interest, partly as sources of oxygen.

We see also, because of the discussions that have occurred at Montana State in generating these proposals, considerably more interdepartmental activity developing. Actually the physics department is heading into two other areas. One is the development of a more complete program in astronomy. There is no astronomy program on the campus now other than astrophysics, and we would like to expand this. The second is expanded work in geophysics of various sorts. Strangely, this work is encouraged by the instrumentation developed in connection with the water resources program in which an entire water shed is being instrumented for water resources study. Much of this instrumentation can be applied to certain geophysics problems that are of considerable interest in our area.

I think the kind of support that we have received from NASA has been vital, absolutely central to the development of much of the research in the physics department; this, in turn, is now spawning and generating research in related areas. Dollar for dollar we can point to a performance at Montana State of which we are very proud. I think that our prospects for the future are excellent and we are looking forward to continuing along the same line.

Space Research at Texas A & M University

Harry E. Whitmore

DIRECTOR, SPACE TECHNOLOGY DIVISION

TEXAS A & M UNIVERSITY

THE RESEARCH PROGRAM BEING CARRIED OUT at Texas A & M University under the NASA Interdisciplinary Research Grant will be discussed. Mention of the new Space Research Complex will be made, and some individual research projects that are not supported by the Interdisciplinary Grant but are related to it will be described. This research grant and the method of handling are both quite satisfactory. Mainly the grant has been used as seed money to develop new programs and areas of research. To some extent ambitious projects have been undertaken but with fairly tight control. Only a very few of these projects were unsuccessful.

Since the grant started in 1962, 16 projects of varying magnitude have received support. For the type of research discussed here, the breadth of the program will be described briefly with comments on some other projects.

The original project of plasma acceleration was in reality quite ambitious on a rather limited budget. The intention was to conduct a plasma research program aimed at the theoretical aspects of the highest specific impulse possible using a plasma. Actually, this project could only be considered a partial success. It resulted in a mediocre plasma facility and a study of the properties of argon. The work is no longer receiving funds.

Studies basic to closed minimum volume biological waste utilization units evolved in an interesting way. Some years ago, a method using antibiotics was worked on to preserve fish. With this work as background, the reverse of this process and the effects antibiotics and other foreign substances would have on a biological waste utilization system if used in the space effort were considered. It turns out that biological systems are grossly affected by many substances that could easily find their way into the system. Since NASA has little interest in

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biological systems at the present time, the work is no longer funded under the research grant. This effort has resulted in a separate project that could greatly reduce the volume of water required by commercial sewage disposal plants, a "spin off" from the space program. This appears to be a popular expression during budget time.

Heat transfer from plasma jets is a basic research effort to obtain better information on the mechanism of heat transfer from a plasma to the containing walls. This investigation is determining under what conditions (1) forced convection predominates, (2) radiation predominates, and (3) both methods contribute to heat transfer.

Scattering of pulsed laser light from plasma was supported from the research grant for a short period at its initiation. Other sources are now supplying support. Here, an effort is being made to use the scattering effect of a plasma on a laser beam to measure the internal properties of the plasma. The obvious advantage of such a method is the absence of a disturbing physical probe.

A mathematical investigation of the structure of light metals has led to work on energy-band calculations of crystalline solids. A year was spent working on this with Dr. Slater of MIT in this field, who is at present converting a number of computer programs from the cooperative computer laboratory of MIT for use on the Texas A & M 7094 computer. Then the electron structure of boron nitride, germanium, and silicon will be investigated.

In an investigation of the structure of long-chain molecules, the basic structure in polymer crystals such as polyethylene is being studied in an effort to explain certain forms of growth. An attempt has been made to demonstrate the methods of growth by showing an epitaxial growth of a salt crystal on the surface of the material. Experiments indicate that salt, lead dibromide ($PbBr_2$), can form such epitaxial crystals if there is considerable surface order.

The directional intensity of cosmic ray muons at energies above a few billion electron volts by use of several spectrometer telescopes is being investigated. One installation will consist of spark chambers, scintillation detectors, and other counters in conjunction with two large, solid, iron magnets. Particles will be deflected as they pass through the high magnetic field inside the saturated iron. This apparatus will be adjustable as to acceptance direction but will be stationary in the laboratory and will be used for detailed and long-term studies of muons at energies above about 5 billion electron volts.

The other type of muon spectrometer-telescope will be smaller and less massive, sensitive to muons of low as well as high energy, and equatorially mounted to scan the celestial sphere and the interplanetary environment in a systematic way. Anisotropies and intensity variations will be sought and monitored.

The main program will be carried out near sea level (College Station, Texas), but a schedule of measurements at a mountain altitude is planned for the future (we hope within a year after the end of the first year of the present proposed work).

This research is of interest to NASA because of its bearing on interplanetary radiation and fields, on high-altitude cosmic-ray phenomena in the Earth's atmosphere, and on the galactic cosmic radiation.

The project concerning space structures constitutes the most ambitious program at Texas A & M involving about 15 persons in Aerospace Engineering and Structures. Investigation is underway in three areas: (1) impact attenuation devices, (2) shell structures, and (3) aerospace materials. Under impact attenuation, the areas being considered are: (a) frangible tubes, (b) tube buckling, (c) collapsible legs, and (d) honeycomb compression.

The shell research is basically concerned with the structurally anisotropic, thin, elastic shell. In particular, it is concerned with an attempt to find a compliance between the elastic constants of an intrinsically anisotropic shell and the physical parameters of a corresponding structurally anisotropic shell.

The materials program addresses itself to the effect surface irregularities have on the properties of ultra-high-strength materials.

The purpose of the research project on the solution of elasticity problems using boundary conditions obtained experimentally is to develop rapid methods of calculating stresses in irregularly shaped bodies. Such methods will be of value in the solution of problems relating to the space program and to other fields as well.

Initially, research is to be concentrated on theory and experimental techniques dealing with two-dimensional stress problems. This is necessary to pave the way for solving three-dimensional problems of stress analysis. The procedures to be followed are:

(1) The establishment of a computer program that completely evaluates the state of stress at all points, corresponding to input data in the form of boundary conditions.

(2) The investigation of various experimental techniques for evaluating these boundary conditions.

The project that involves the relation between viscosity and circular-pipe experimental data for non-Newtonian flow of solid propellants investigates the characteristics of non-Newtonian fluids as they apply to the handling of solid propellants.

The investigation of properties in radiation-damaged solids at low temperature is establishing the damage that can result in the combined environment of cryogenic temperatures and high radiation fluxes.

From this point on, the projects discussed are desirable to start but for a number of reasons have not been initiated. This would involve heat-transfer reentry work using an arc-driven shock tube. The main effort would initially be concerned with the surface catalytic effect produced by the recombination of particles on the surface involved. That is, for two particles to recombine or associate, they must release energy to the surface. What is this effect?

Admittedly, this is a brief description of the research being conducted under the Texas A & M interdisciplinary grant. Detail results of these projects are available in reports to NASA.

In the area of activation analysis at Texas A & M, work in this field was begun about 6 years ago. So far, the computing center and the Institute of Statistics have had excellent results with automated, computer coupled, activation analysis. The process of neutron bombardment of a sample followed by an analysis of the resulting gamma-ray spectrum gives a nondestructive analysis of the sample. Of interest to NASA is that this method can provide a real-time analysis both quantitative and qualitative of the surface of the moon or planets. It is the opinion of the people at Texas A & M that such a device would weigh about 30 pounds. At the present time, work is being performed on the basic problems in providing such an experiment.

Session III—Research

Chairman: **John T. Holloway**
Deputy Director
Office of Grants and Research Contracts, NASA

Coordinator: **Edward R. Redding**
Office of Grants and Research Contracts, NASA

N66-12411

The Multidisciplinary Grant as a Mechanism for Support of Basic Research in Universities

Willard F. Libby

DIRECTOR, INSTITUTE OF GEOPHYSICS AND PLANETARY PHYSICS
UNIVERSITY OF CALIFORNIA

FROM THE VERY BEGINNING, it has been apparent to a few in the academic community that the success of the national space program depends to a very large degree on the quality and extent of involvement by universities. Their most important contribution would naturally be in doing the job that they are uniquely qualified to do, that is, to educate and train the scientists, engineers, and other professional personnel required by such a massive program. To do this, however, the universities would have to receive substantial assistance from NASA.

THE BEGINNING OF A PARTNERSHIP

It has been 3 to 4 years since the beginning of NASA's awareness of the importance of the universities' role in the national space effort. It was then that NASA began to experiment with the multidisciplinary research grants and facility and traineeship grants. These steps, we believe, were specifically designed to strengthen the graduate educational programs in the space-related fields in the universities. It can be said without fear of contradiction that 3 years ago the University of California, Los Angeles, was almost totally unaware of the opportunities for both basic and applied research afforded by the nation's space efforts. I am sure this same ignorance was prevalent about the country. The situation at UCLA and, I believe, nationally is changing. At UCLA, the support derived from the NASA Sustaining University Program and our own efforts have helped to forge a partnership of extraordinary value to both parties.

What I have said is not intended to imply that NASA was inordinately slow in recognizing the important potential of the universities' resources. It was a young organization and had much to do. Some things had to be deferred. Perhaps we should be more concerned that the scientific community has not been sufficiently alert to grasp the opportunities afforded by the national space program.

A good start has now been made. I have no complaints about the quality of the basic university program which NASA has developed. Yet, it is no secret that I believe NASA is not doing enough to support education in the universitites and to encourage science.

THE NASA SUSTAINING UNIVERSITY PROGRAM

The NASA Sustaining University Program has been developed in response to the needs of the National Aeronautics and Space Administration. It is not my task to discuss all aspects of this fine effort. However, I have been asked to describe the activities supported by our multidisciplinary grant and its relation to the other forms of assistance.

To my knowledge, UCLA has the only program in which all three types of grants—the multidisciplinary grant, the facilities grant, and the training grant—are administered by the same body. To us, however, this seems not only reasonable but highly desirable if we are to achieve maximum progress in graduate education in the space-related fields.

From the beginning, UCLA was determined that the role it played in the space program must serve not only the national interest but should also be looked upon as an opportunity to strengthen graduate education. It was for this purpose that the Chancellor appointed a committee to shape the policy which would guide, coordinate, and direct UCLA's efforts in the space-related fields.

The committee has adhered to the principle that as an institution of higher learning, UCLA could contribute best to the national space effort by fulfilling its educational responsibilities and obligations in the space-related fields. This is especially appropriate inasmuch as UCLA is the only fully developed tax-supported graduate school in southern California, the area with the greatest concentration of aerospace industry in the nation. The committee has been effective in seeing that every dollar invested by NASA in UCLA has been used efficiently to those ends.

Graduate education in the sciences and engineering strongly depends on the quality of the research at the institution and the opportunities provided for graduate students to participate. In turn, many factors contribute to the quality of research including faculty, facilities, support funds, and graduate students. Through its assistance in strengthening each of these elements, NASA is helping UCLA to build a strong cohesive program in space science.

THE CATALYTIC ROLE OF NASA FUNDS

Inasmuch as UCLA and NASA were almost complete strangers 3 years ago, it seemed important to devise a program that would reach a significant number of faculty, graduate students, and, hopefully, undergraduate students. If UCLA were to play a leading role in space education, it was apparent that some sort of a grant instrument which would provide greater flexibilty than the ordinary project grant affords would be needed. This instrument would ideally supply us with the means to support new space-related research projects in the physical sciences, biosciences, and engineering and to adjust our support for ongoing projects in order to take full advantage of interesting new developments. The University needed a method of support capable of promoting quick response by major university elements to the new challenges posed by space exploration.

Funds from the multidisciplinary grant have been used in a number of ways to stimulate and strengthen the interest in space-related research at UCLA, a stated objective of the UCLA Space Program. These funds have been used to bring new researchers to the campus, to bring visiting scientists for short periods for intimate exchange of new ideas, to support three or four continuing programs of a major nature, and to help to get new research started. While the first three activities are important, most of our resources go into the latter.

In the 3 years UCLA has administered a multidisciplinary NASA grant, we have aided in bringing 37 visiting scientists to the campus for short periods of time. This grant has supported 14 visiting researchers for periods of up to 1 year. Through the use of these funds and program enrichment funds from the NASA predoctoral traineeship grant, we have aided in bringing seven new faculty members to the campus to augment the existing faculty in space-related fields. It should be noted that the continuing appointments of all the new faculty are funded solely from regularly budgeted University funds. Finally, we have made over 50 subgrants to faculty for new starts on space-related research in various areas—biology and medicine, physical sciences, engineering, and business administration. We believe this seed money is beginning to pay large dividends.

THE EFFECTIVENESS OF THE MULTIDISCIPLINARY GRANT

The effectiveness of the multidisciplinary grant can be measured in a number of ways: the number of new faculty whose main interests are directly or indirectly related to space science or engineering; the growth of graduate enrollment in the space sciences; publication of research papers; and the number of research projects initially supported from this grant which have successfully advanced to a stage where they could attract extramural support on their own merits.

There is a better criterion, however. In our view, the direct and indirect assistance this type of grant provides to graduate students is the most important aspect and the truest measure of the value of this assistance. In this regard the funds have been spent well. In the last 3 years over 46 faculty members have received support from the general funds, and they in turn have provided support to over 45 research assistants and other graduate students. In addition, several professional research personnel and visiting scientists and over 50 undergraduates have derived support from these funds.

It must be emphasized that the research activities and the support facilities funded from this grant provide an extremely important form of auxiliary assistance to the NASA predoctoral trainees. These funds, in fact, help to start or keep going many projects of direct interest to the trainees. Without this grant the opportunity range for space-related research would be greatly narrowed.

There is no doubt that this type of support is indispensable to space education. Educational efforts such as ours will make future space exploraton meaningful. Although much of value will undoubtedly come from the research currently supported from the multidisciplinary grant, the real payoff for the space program will come only if we succeed in stimulating and disciplining these bright young minds now in our charge in the right way.

VISITING SCIENTISTS PROGRAM

I should like to describe one aspect of our program which we think is extremely important, although the cost is quite modest. By employing NASA 237 funds in conjunction with the training grant institutional allowances and University funds, we have been able to make a variety of arrangements for visiting scientists. In general we try to provide maximum exposure of the visitor to our students and the faculty. This system has great flexibility and permits nearly instantaneous action, a highly important feature if advantage is to be taken of all the opportunities to bring top-notch visitors to the campus. This program is aimed primarily at stimulating interest in space science on this campus among our students and staff. We think it has been effective in that sense.

CONCLUDING REMARKS

Before turning to specific examples of research supported from the multidisciplinary funds and more interesting new developments, I should like to draw a few general conclusions based on our experience with this type of grant.

1. Although the multidisciplinary grant cannot and should not replace the project grant, it is a highly useful mechanism for achieving broad objectives set by an institution. In our case, the general goal was to develop a major program in space education and research at UCLA.
2. The administration of this type of grant poses, on the whole, no more of a problem to the institution than would a number of project grants totaling the same amount.
3. Greater flexibility in the application of the funds is afforded the institution. Of course, great care must be taken to see that proper use is made of the funds. We follow a practice of keeping NASA totally informed of our activities. In cases where the committee itself is uncertain, prior approval is sought for the action contemplated. Thus NASA always has the opportunity of telling us what they do not like that we are already doing, or of not approving a proposed action.
4. From our standpoint this system has worked very well. Homer Newell and Tom Smull will have to tell you how well it works from NASA's point of view.
5. I believe use of this type of grant will increase, not only by NASA but by other agencies as well. Certainly this will be so if the sponsoring agencies can see that they are getting a good return for their money. I might mention that the National Science Foundation has supported the Atmospheric Research Laboratory at UCLA and San Diego for the past 5 years under a similar grant. The Atmospheric Research Laboratory under the direction of Gordon MacDonald at Los Angeles and Walter Munk at San Diego has been highly successful.

SOME ACTIVITIES SUPPORTED BY NASA 237–62

I. MAGNETICALLY SHIELDED TEST FACILITY

Investigator: **P. J. Coleman, Jr.,** *Research Assistant*
Institute of Geophysics and Planetary Physics

In order to provide a magnetically quiet region in the laboratory, we have constructed a magnetically shielded test facility. This facility is used mainly in testing and calibrating relatively sensitive magnetometers. It is also used in determining the magnetic properties of materials which produce relatively weak fields. Measurements of the latter type have been performed mostly in an effort to determine the magnetic characteristics of particular spacecraft by measuring the fields produced by the spacecraft subsystems.

The heart of the facility is a magnetically shielded chamber with a cubical working volume 8 feet on a side. Centered in this working volume is a triaxial system of Helmholtz coils. The diameters of the coils are about 3 feet. Centered within this coil system is a cylindrical temperature chamber with a working volume 11 inches in diameter and 16 inches high. Mountings for magnetometer probes are centered within the temperature chamber.

Thus, the magnetically shielded chamber is used to attenuate the fields from man-made and naturally occurring magnetic noise; the coil system is used to produce known, accurately controlled fields within this relatively noise-free region; and the temperature chamber is used to vary the temperature of a magnetometer probe at the same time that the response of the magnetometer to known fields is being tested.

Figure 1.—Inside view of a magnetically shielded chamber.

Figure 1 shows a view of the inside of the room. Note (from bottom to top) the mounting table, the Helmholtz coils, the open temperature chamber, and the duct which carries the thermally con-

Figure 2.—A more extensive view of the partially completed magnetically shielded chamber.

trolled air to the chamber. Figure 2 shows a more extensive view of the partially completed chamber. Note the water-cooled metal ducts that allow the thermally controlled air to pass through the walls of the shielded chamber without changing the temperature of the shielding material in the walls. In order to further stabilize the temperature of the shielding walls, the temperature-change heat losses from the temperature chamber are eliminated by an air-conditioning system that maintains the air temperature within the shielded chamber at a constant value.

This shielding material is molybdenum permalloy steel, alloy 4–79. The walls contain two layers of this material. Each layer is a sheet 0.070 inch thick. The sheets are separated by 6 inches.

The chamber is presently being used in testing magnetometers for the Mariner spacecraft, the Orbiting Geophysical Observatory, and the Advanced Technological Satellites.

II. PLASMA STUDIES

Investigators: **W. F. Libby,** *Director, Institute of Geophysics and Planetary Physics*
Carl Jensen *and* **Lowell Wood,** *NASA Predoctoral Trainees in Chemistry and Geophysics*

We have recently developed a system for creating large volumes of dense, high-temperature plasma for use in laboratory studies of this

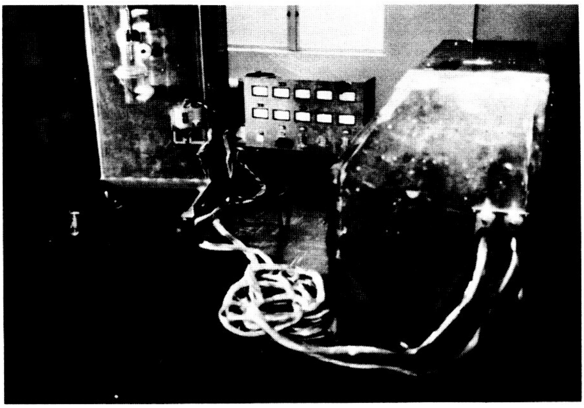

Figure 3.—Principal components of system developed for creating large volumes of dense, high-temperature plasma.

fascinating state of matter. Figure 3 shows the principal components of this system. The large cabinet on the left contains the power supplies for a large high-frequency oscillator, contained in the cabinet on the right. The main control panel for the system is in the center.

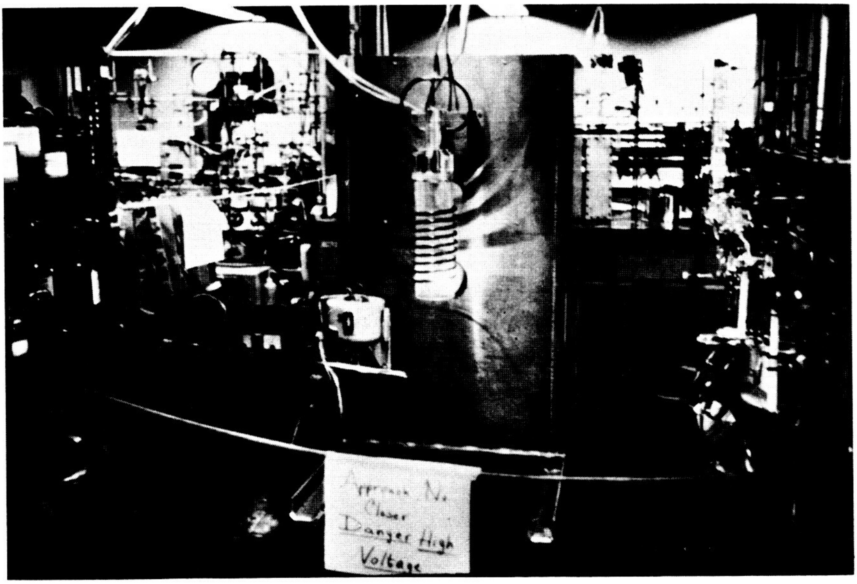

Figure 4.—Low-power demonstration of plasma generator.

Figure 4 shows the unit in operation for a low-power demonstration. The radio frequency energy is transferred from the coil about the plasma volume to the plasma by means of the induction field arising from the double application of Maxwell's equation for the circulation density of the electric field. The possibility of transferring power from an oscillating circuit to a conducting load of this type was first realized by Lord Kelvin and the American Nikoli Telsa in the 1890's, and the first electrodeless plasma generators were built by them. This very promising field lay neglected for 40 years until a Russian, George Babat, rediscovered it in a remarkable series of experiments in Leningrad during the German siege. Nearly two more decades elapsed before much interest was shown in this type of work, and our group at UCLA has been only one among many who have recently made a second rediscovery of the earlier work; it seems likely that interest in this type of apparatus will not go into a similar decline in the foreseeable future.

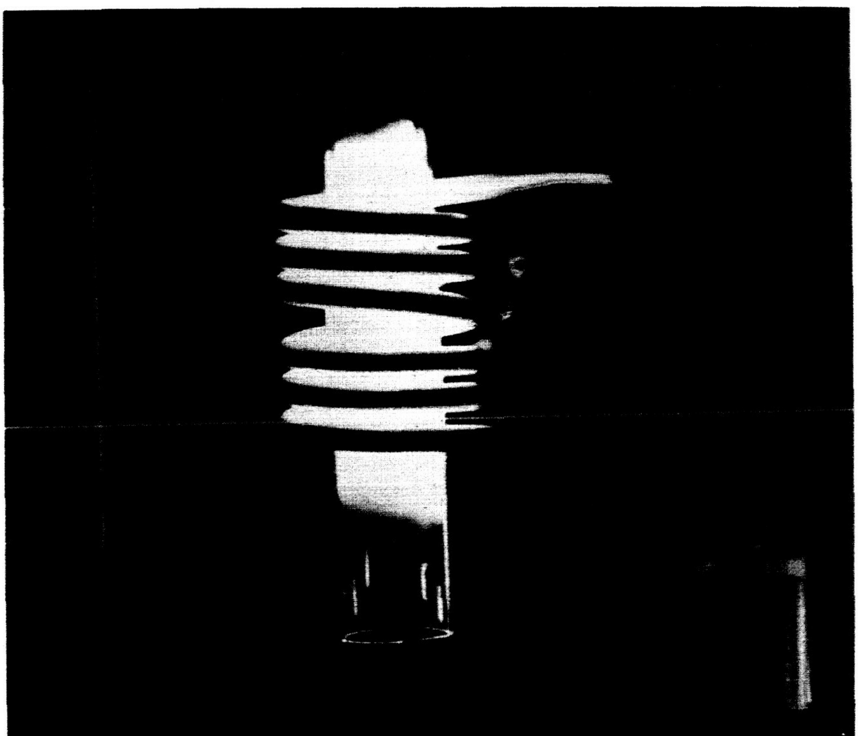

Figure 5.—Streaming helium plasma contained in a gas sheath formed by quartz tubing.

Figure 5 shows a streaming helium plasma contained in a gas sheath which is formed by quartz tubing. We have been able to generate liter volumes of highly ionized plasmas of all the commonly available gases at atmospheric pressures, corresponding to temperatures of many tens of thousands of degrees Kelvin; the maximum continuous power available from the unit is ½ megawatt and it has a pulse capability in the multimegawatt range. Oscillating electric fields in the kilovolt/centimeter range may be obtained.

We have carried out a large number of studies on plasmas of various kinds at atmospheric pressure and below, both with regard to their magnetohydrodynamic and radiative properties and their usefulness as heating agents for various refractory materials. The unique feature of the electrodeless plasma generator, namely the ability to create a plasma without touching it with a material object, thus avoiding apparatus vaporization and plasma contamination, plus the possibility of rapidly changing the input power and the related plasma parameters, has been most useful in this work. We expect to have soon results from these studies, which range from areas in astrophysics to those in materials science.

III. CHEMICAL EFFECTS OF IONIZING ULTRAVIOLET LIGHT

Investigator: **Carl Jensen,** *NASA Predoctoral Trainee, Chemistry*

Investigations are underway to determine the chemical effects of ionizing ultraviolet light, which is created in abundance by the sun, but filtered from the earth by the upper atmosphere. Mass spectrometric studies and other studies indicate that this light, found only in space, may be responsible for some unusual and very interesting kinds of chemical reactions.

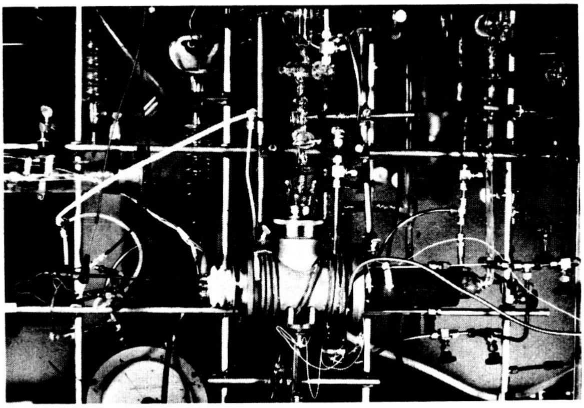

Figure 6.—Extreme ultraviolet light source and irradiation cell, with attendant vacuum, electrical, and water cooling lines.

Figure 6 shows the extreme ultraviolet light source and irradiation cell, with attendant vacuum, electrical, and water cooling lines. The source, located in the horizontal stainless-steel cylinder and powered by the combination electrical and water lines entering through the insulator, emits 584° Å helium light as a result of electronic recombination in a 2000° K continuous helium plasma. This light is passed through a window made of aluminum foil 0.000008 inch thick which filters out the longer wavelengths present. The light then enters the glass irradiation cell whose vacuum and gas handling connections are visible at the bottom of the vertical cylinder connected to the horizontal one. At present the chemical species being irradiated is methane.

IV. 24-INCH TELESCOPE

Investigator: **L. H. Aller,** *Professor of Astronomy, Chairman of Astronomy Department*
G. O. Abell, *Associate Professor of Astronomy*

Arrangements have been made for California Institute of Technology to construct a 24-inch telescope to be utilized by graduate students and staff of UCLA. An increasing number of problems in observational astronomy can be handled with instruments of modest size, which can provide the users with experience in modern observational techniques. Some of the problems which might be practically attacked include photoelectric observations of binary and variable stars, novae, and supernovae; positional work on comets, minor planets, and satellites; and direct lunar and planetary observations. In addition, this instrument could also be used to test equipment intended for use on larger telescopes or on space vehicles.

The telescope is designed to be quite versatile—to be quite useful in either visual or infrared work. A unique feature in the design is that the Cassegrain focus is available at either end of the declination axis. This arrangement permits the observer to use either of two pieces of equipment without removing them from the telescope; it is merely necessary to rotate the Cassegrain flat. One could, for example, have photoelectric equipment at the focus on one end of the declination axis and a plate holder for direct photography at the other end; thus, one could use one or the other alternately without changing equipment. The telescope's design incorporates features usually found only on larger instruments.

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NASA's Contributions to Space Sciences and Astronautics at Princeton University

Martin Summerfield

PROFESSOR OF AEROSPACE PROPULSION

PRINCETON UNIVERSITY

WHEN THE CONGRESS IN 1958 PASSED THE LEGISLATION that established NASA, it wrote into the National Aeronautics and Space Act the following broad objectives among others:

(1) The preservation of the role of the United States as a leader in aeronautical and space technology and its peaceful applications
(2) The expansion of human knowledge
(3) The improvement of the technology of aeronautical and space vehicles
(4) The utilization of the scientific and engineering resources of the Nation as effectively as possible

These clauses in the Act provide the basis for the wide-ranging technical program of NASA in scientific space exploration, in manned space flight, in advanced research and technology, and in practical space systems. Equally well, they provide the basis for a partnership on a national scale between NASA and the Nation's universities.

To preserve the role of the United States as a leader in aeronautical and space technology and its peaceful applications, and to expand human knowledge, clearly requires among other things the expansion of university education in scientific, engineering, and nontechnical areas important for aeronautical and space development. At the same time, research contributions from the university community, when properly stimulated, can strengthen greatly NASA's aeronautical and space programs. Thus, the partnership involves both education and research, and it must be viewed as a joint effort in which each partner takes into account the proper objectives of the other.

It has been Princeton's experience, in its cooperation with NASA, that the partnership has been highly productive, in relation to the objectives laid down by the National Aeronautics and Space Act. The main part of this paper constitutes a report on the NASA-sponsored program at Princeton, to illustrate the results of the partnership to date.

It deserves to be stated at this point that, while Princeton has specifically oriented some of its educational and research activities toward the long range objectives of NASA, the fundamental educational purposes of the University have not been compromised, and the faculty as a whole is pleased with the partnership. Partly in response to concerns over the possibility that orientation of this kind in some parts of the University might upset its educational traditions, the chairman of the University Research Board wrote with regard to such support as follows in his annual report to the Trustees:

This has made it possible to enlarge the graduate school, to improve graduate instruction, and to improve the quality of the faculty both by hiring able people and stimulating men already here. Indirectly the quality of undergraduate education has been improved. By relieving the strain on general funds, sponsored research has helped departments not directly involved. . . . Support for work consonant with the general purposes of the University has enabled Princeton to strengthen its position as a leading university making appropriate contributions to the intellectual vigor of the Nation and educating men to fill positions of responsibility in the modern world.

Now, to return to the main principle of the NASA-University partnership, there is more to it than simply financial support of the University's educational objectives. There are the specific programs within the University sponsored by NASA, that support NASA's objectives. Of the various projects at Princeton sponsored by NASA, three important areas are to be discussed here. They are (1) the research program in astrophysics; (2) the research program in aerospace propulsion; and (3), the graduate level traineeship program.

NASA-SPONSORED RESEARCH IN ASTROPHYSICS

In the Arstrophysics Department a broad program of astronomical observations is underway under NASA cosponsorship, employing telescopes placed above the earth's atmosphere to accomplish better photographic definition and to make measurements in spectral regions in which the atmosphere is opaque.

In 1957 Stratoscope I, a 12-inch diameter balloon-supported telescope, was launched in the first of a series of flights at altitudes above 80 000 feet. The theoretical resolution of this first model was only about 0.4 second of arc in the visible region, not much better than the best of ground-based telescopic photographs obtained under good night seeing conditions. However, Stratoscope I was an excellent instrument for daytime observations of the sun's surface, free of glare and free of atmospheric distortion, and it revealed details never before resolved and obtained meaningful sequences of photo-

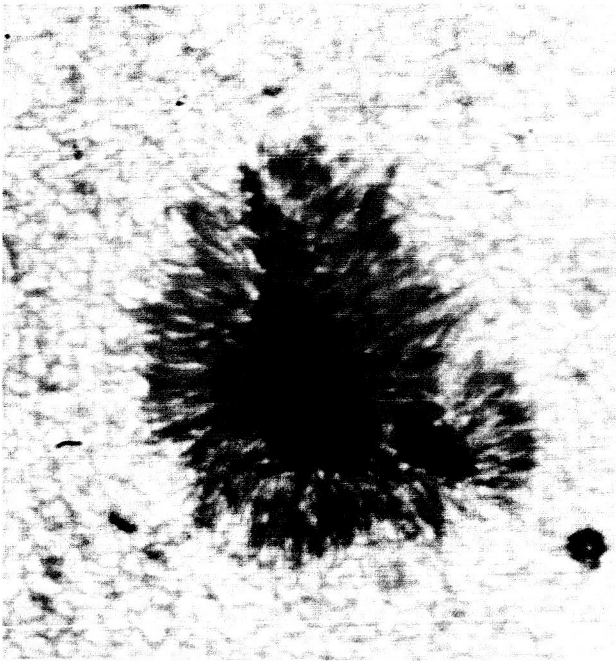

Figure 1.—Sunspot photographed by Stratoscope I.

graphs, so that the dynamics of the surface could be studied. Figure 1 is a photograph of a sunspot obtained with Stratoscope I.

To improve on the atmosphere-limited resolving power of ground-based telescopic systems for observations of night objects (planets, stars, and galaxies), a larger balloon-supported telescope called Stratoscope II was developed. Its diameter of 36 inches gave a theoretical diffraction-limited resolution of 0.14 second of arc at 5000 angstroms, three times better than the occasional best of ground photographs taken with large telescopes. To achieve this resolution in practice required the development of an accurate attitude control and stabilization system, a special frictionless support and bearing system, and an optical alinement system that could cope with shifting stresses during attitude changes and with potential distortions during temperature changes in flight.

Figure 2 shows the arrangement of the equipment with the telescope and the side-arm unlatched. In the first series of flights, Stratoscope II was used to obtain infrared spectra of planets and stars. The con-

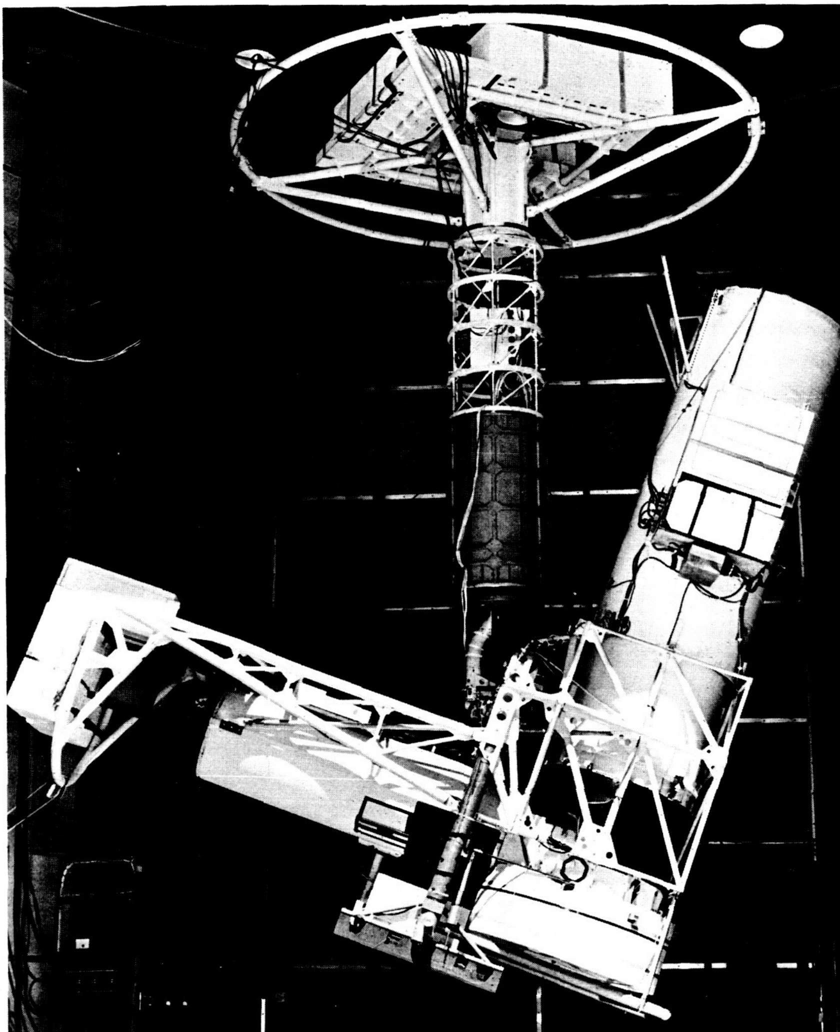

Figure 2.—Stratoscope II with spectrographic side-arm unlatched.

figuration shown in figure 2 shows the infrared spectrometer joined in a side-arm to the telescope. Currently the Stratoscope II is being test flown in its photographic configuration. The balloon being readied for launch is shown in figure 3, and in figure 4 Stratoscope II is seen in its ascent. Recovery is achieved by releasing helium from the balloon by remote control, and in emergency, by parachute. The balloon is tracked steadily by radar and by aircraft.

The Stratoscope program is sponsored jointly by the National Science Foundation, the Office of Naval Research, and NASA. Strato-

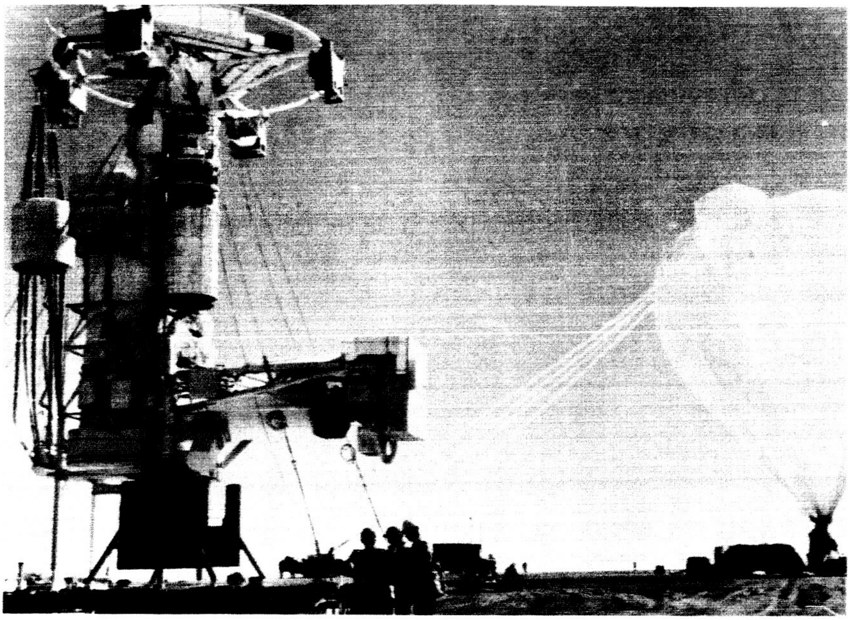

Figure 3.—Balloon ready for launch (courtesy National Science Foundation).

scope II was designed and developed by the Perkin-Elmer Corporation under a subcontract from Princeton University. The infrared spectrometer is derived from a collaboration with the Space Sciences Laboratory of the University of California at Berkeley, a NASA-sponsored program. The balloon flights originate from the NCAR Balloon Base at Palestine, Texas.

Another major phase of NASA-sponsored research with telescopes above the atmosphere was entered in 1963 when Princeton continued the development of astronomical equipment for a large satellite observatory under NASA contract. The research into the design features of a high-resolution spectroscopic satellite had been initiated under Air Force contract in 1959.

The satellite will, of course, orbit the earth at a height well above the ozone layer, which extends to about 40 miles. (Stratoscope II rose to only 16 miles, enough to get above atmospheric water vapor and the twinkle of the atmosphere, but not enough to get above the ozone.) From a satellite station about 500 miles up, beyond ozone and almost everything else, far ultraviolet astronomy becomes possible. The Princeton Experimental Package for NASA's third Orbiting Astronomical Observatory (OAO) is designed to operate in this spectral range from 700 to 3200 astronomical units. The satellite will observe stars as faint as the sixth visual magnitude and it will

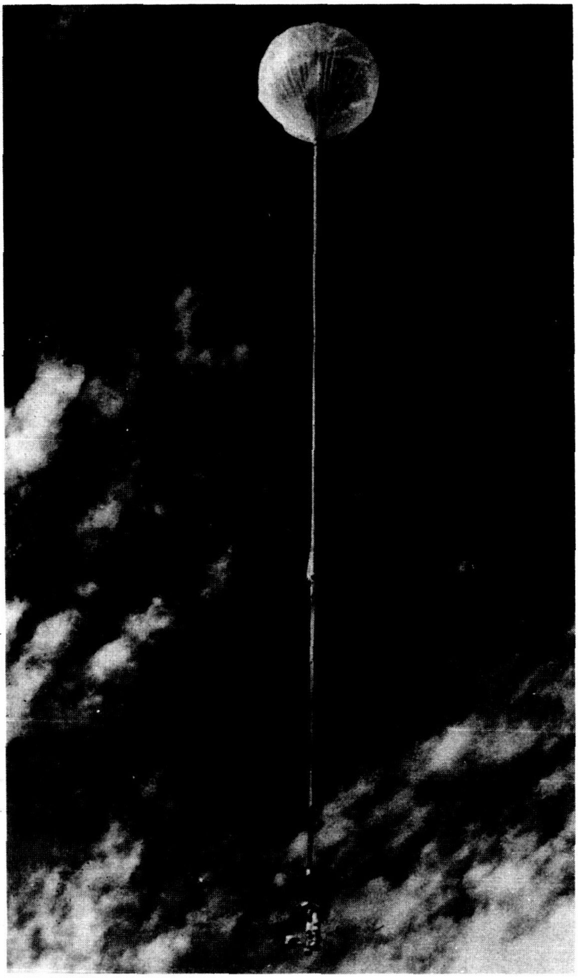

Figure 4.—Stratoscope II on its way up (courtesy National Science Foundation).

study the composition of interstellar gas and dust clouds. Important questions of stellar structure and the structure of the universe may be answered by these ultraviolet measurements.

The OAO Spacecraft is being constructed under NASA contract by a private aircraft corporation. The design and construction of the Princeton telescope, its controls, and data handling system is being carried out under a Princeton subcontract with private industry. Launch is programed to take place from Cape Kennedy in 1968, on top of an Atlas-Agena rocket.

A mockup of the satellite at the aircraft plant is shown in figure 5. The stabilization system is designed for 0.1-second-of-arc accuracy. The telescope with a 32-inch reflector will be mounted in the centerbody as shown in figure 6. The all-up launching weight will be 3600

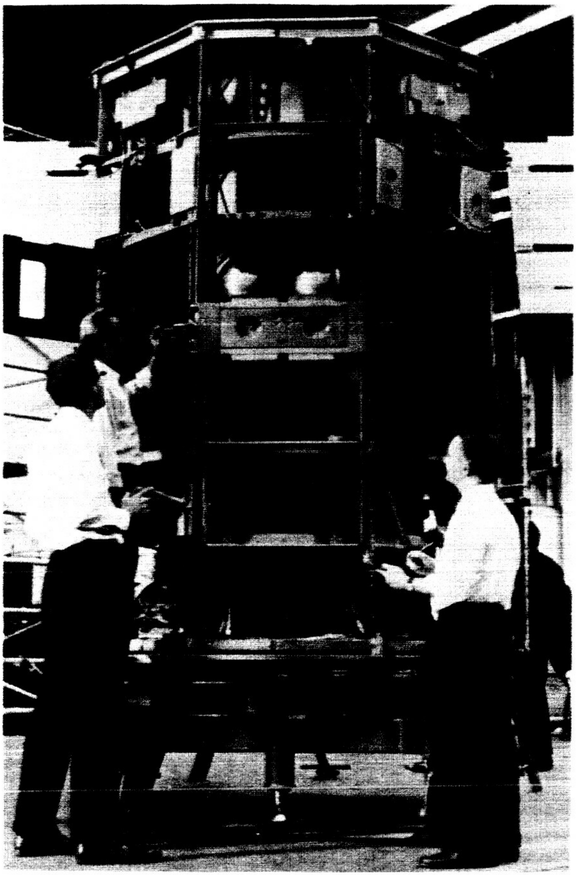

Figure 5.—Orbiting Astronomical Observatory (OAO) satellite mockup.

pounds, about one-third representing the Princeton telescope and associated equipment. Figure 7 shows the optical arrangement, with the ultraviolet spectrograph in position.

To gain some advance experience with above-the-atmosphere ultraviolet measurements, several Aerobee Sounding Rockets carrying small ultraviolet spectrometers are being launched from White Sands Missile Range in a current program of flights. Although the up-and-down time above the atmosphere is only a few minutes, it is possible to obtain useful spectra both by photographic recording and subsequent recovery and by photomultiplier detection and radio-link data transmission.

An Aerobee nosecone instrumented for photoelectric recording is shown in figure 8. The optical components for photographic recording are shown in figure 9, and in figure 10, the nosecone is being placed over the equipment. A launching in 1964 is illustrated in figure 11.

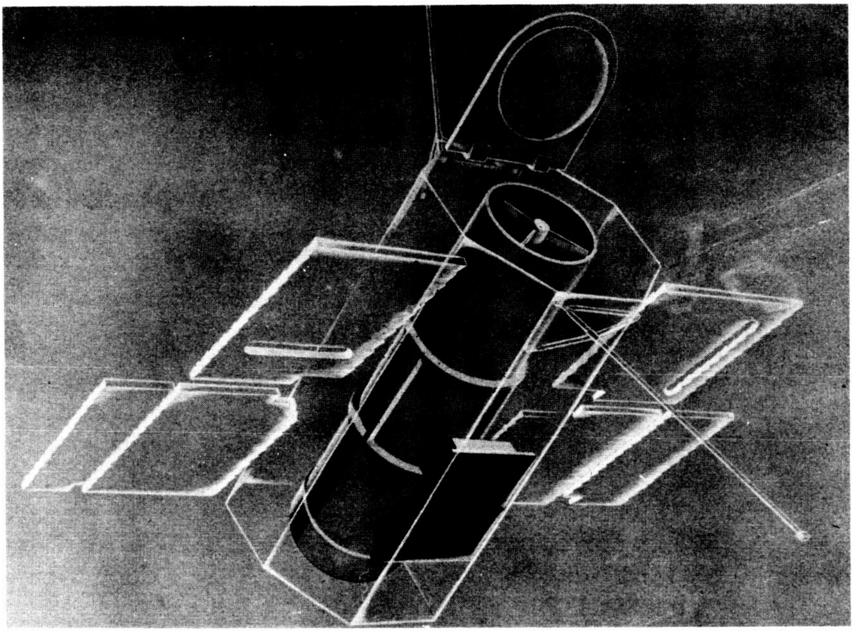

Figure 6.—Mounting of Princeton telescope in OAO satellite (courtesy Sylvania Electronic Systems).

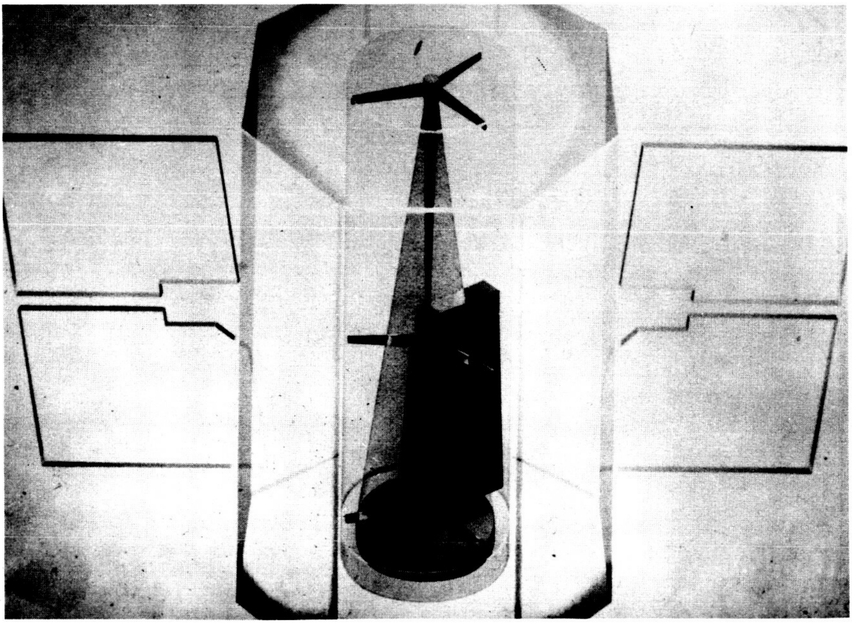

Figure 7.—Optical arrangement for spectrographic measurements.

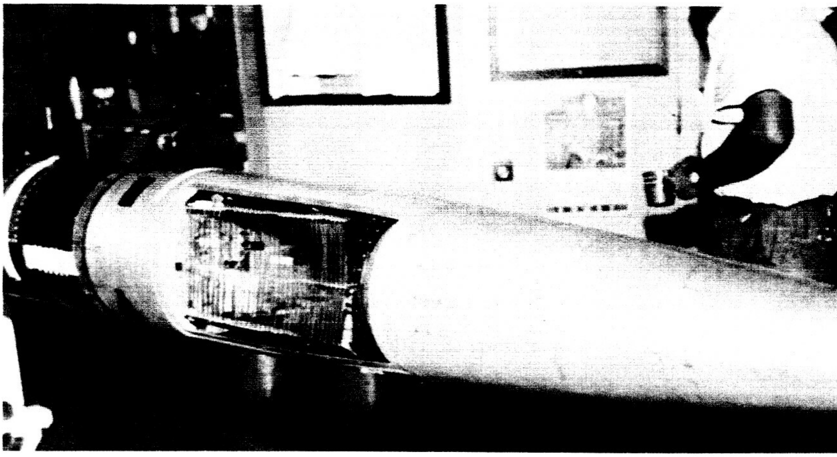

Figure 8.—Aerobee nosecone with stellar spectrometer (courtesy U.S. Army White Sands Missile Range).

Figure 9.—Spectrograph to be installed in Aerobee.

Figure 10.—Attachment of nosecone to Aerobee.

The parachute-recovered package is shown in figure 12. Some preliminary data have been obtained and several additional flights are planned this year.

To supplement all this observational research above the atmosphere, NASA is supporting at Princeton a program of fundamental astrophysical studies, both theoretical and experimental. This includes such topics as spectral emission by extragalactic hydrogen, the effect of line blanketing on ultraviolet stellar radiation, and a novel set of experimental measurements of absolute transition probabilities in the vacuum ultraviolet by pulsed excitation of gases in the range up to 50 megacycles per second.

Graduate education accompanies, of course, this program of research. At present, three graduate students are engaged in research on some of the problems being attacked in this program. Additional students may become involved as results begin to flow from Stratoscope II and from the Princeton OAO.

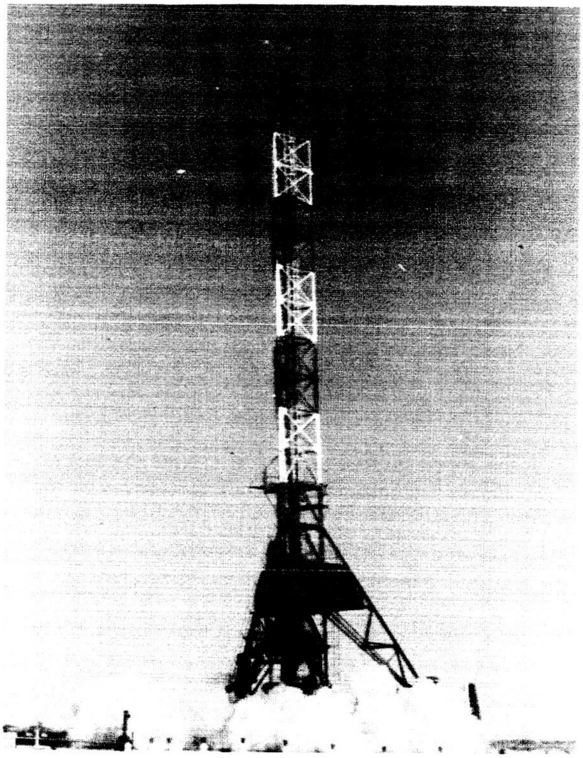

Figure 11.—Aerobee launching in 1964 (daytime launch).

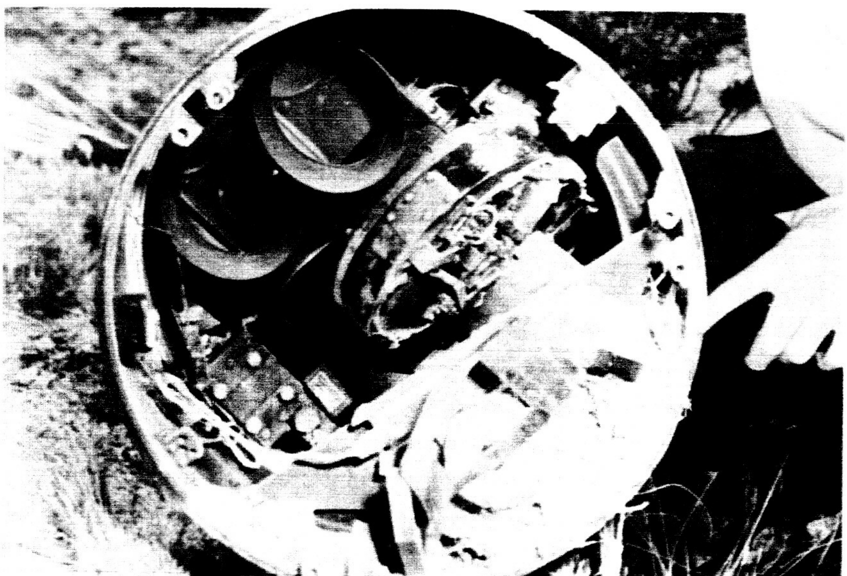

Figure 12.—Spectrometer package recovered by parachute (courtesy U.S. Navy).

NASA-SPONSORED RESEARCH IN AEROSPACE PROPULSION

NASA is concerned not only with the space sciences but also, on the engineering side, with research and advanced technology in astronautics. In the Engineering School at Princeton, NASA is contributing a large part of the sponsorship of a diverse program of research and graduate education in the aerospace propulsion field, an activity that comprises a segment of the Department of Aerospace and Mechanical Sciences. Additional research sponsorship in this program comes from the Air Force OSR, the Navy ONR, and the AEC.

Aerospace propulsion takes many forms, and underlying all these forms, because of their relative novelty and advanced character, are many basic problems that require investigation and solution. There are chemical rockets based on solid propellants, liquid propellants, and hybrid combinations of liquids and solids. There are nuclear rockets with different kinds of solid, liquid, and gaseous cores. There are high-speed atmospheric propulsion systems ranging from the turbojet to the hypersonic ramjet. There are low-thrust electric-propulsion engines based on electrostatic-ion or electromagnetic-plasma-acceleration systems, and there are space powerplants of several kinds in development to provide the electric power for these accelerators. From the viewpoint of a research scientist, the basic problems underlying these and other thrust engines lead toward a broad field of applied science. From the viewpoint of the engineer, all forms of areospace propulsion except the standard chemical rocket are still in the early development stage and require improvement and clever solutions to make them practical.

This is the field of activity, applied science and advanced engineering research, that constitutes the program of the Guggenheim Aerospace Propulsion Laboratories at Princeton. (The name of Guggenheim was bestowed on this set of Laboratories to signify publicly the financial gifts of the Guggenheim family that have initiated and sustained the program in aerospace propulsion at Princeton since 1949, over 15 years ago.)

The program is one that combines both education and research. The educational part is so prominent a feature of the program that it may be advantageous in this Conference to describe the program from the standpoint of education rather than simply in terms of research. Also, the facilities developed for aerospace propulsion research are so unique in a university environment, that NASA's contributions in this field deserve to be discussed.

To give some idea of the scope of the program, it can be mentioned that there are at present 35 graduate students (full time) in this field and they are led by a faculty of five professors and six research engineers of senior rank. Other employees, electronics engineers, designers, laboratory technicians, typists, etc., comprise a supporting staff to provide skilled services in each research project as necessary. Also, there are about five undergraduates and several foreign students engaged in the research.

In the scheme of graduate education as it has evolved in the Aerospace Propulsion Laboratories, virtually all of the research is conducted with graduate students. One way of describing the research program, then, is to show it in terms of graduate students working on thesis projects. This will appear in the photographs, which tend naturally to emphasize the facilities and the experimental researches. It should be realized, however, that in every area theoretical research is conducted as well.

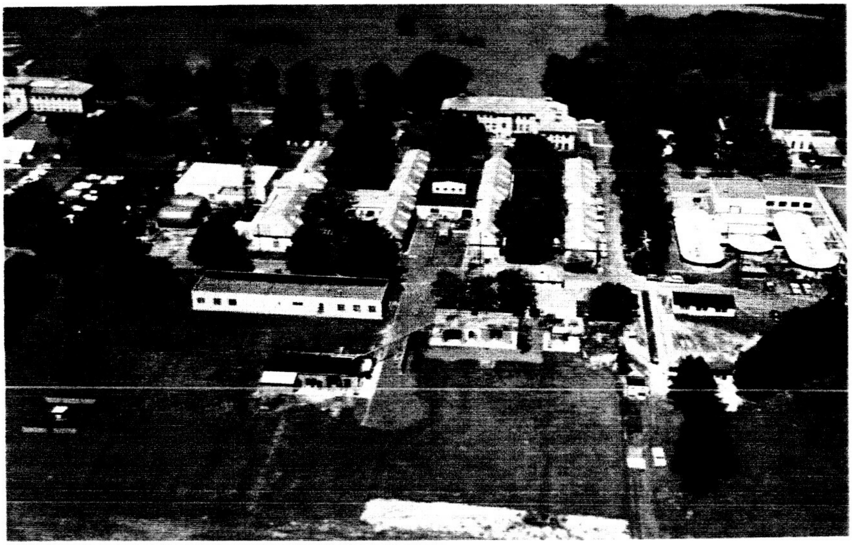

Figure 13.—Forrestal Research Center of Princeton University.

Figure 13 is a photograph of the part of Princeton University that is known as the Forrestal Research Center. At this Center are located the Department of Aerospace and Mechanical Sciences (Graduate Division), most of the laboratories of this Department in which research on astronautical problems is carried out, and research laboratories of other University Departments engaged in nuclear physics, controlled nuclear fusion, etc. The Forrestal Center is not an extra-departmental research organization; it is simply a location that houses research facilities too large to accommodate on the main campus.

The proximity of the lecture halls and classrooms in the Aerospace Sciences field to the laboratories is a great advantage in the graduate educational program. In the foreground are rocket engine test cells, the solid propellant processing laboratory, high-speed wind tunnels, etc., all within 500 feet of the lecture halls in the building at the upper left. Graduate students can conveniently attend lectures and conduct rocket engine experiments during the same day, without having to travel great distances to a remote test station.

The previous photograph emphasized the specialized experimental facilities such as rocket engine test cells and wind tunnels available for graduate student and faculty research. Much of the research, however, is purely theoretical in nature; and in addition, many of the experimental studies are conducted quite conveniently in normal laboratory rooms rather than firing cells. Such "conventional" researches are located in offices and laboratories in various buildings at the Center. A new building is under development to provide office space for faculty and graduate students in Aerospace Propulsion, and to provide laboratory space for experiments of nonhazardous type (fig. 14). Figure 15 shows the architect's drawing of the first part of the new Aerospace Propulsion Laboratory completed and occupied in the fall of 1964. This wing of the building was financed in large part by a grant from the National Aeronautics and Space Administration. Experimental researches on chemical kinetics of combustion, plasma pinch engine dynamics, nuclear propulsion heat transfer, and solid propellant combustion and ignition have been transferred into this building from scattered locations, and the offices have been occupied by faculty and graduate students. Figure 16 is a photograph of the front of the building. It has provided Prince-

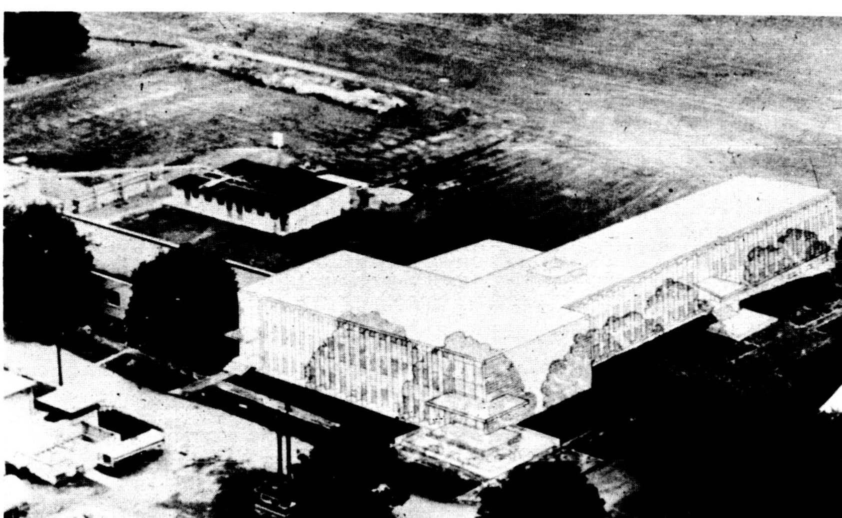

Figure 14.—Design for main aerospace propulsion building.

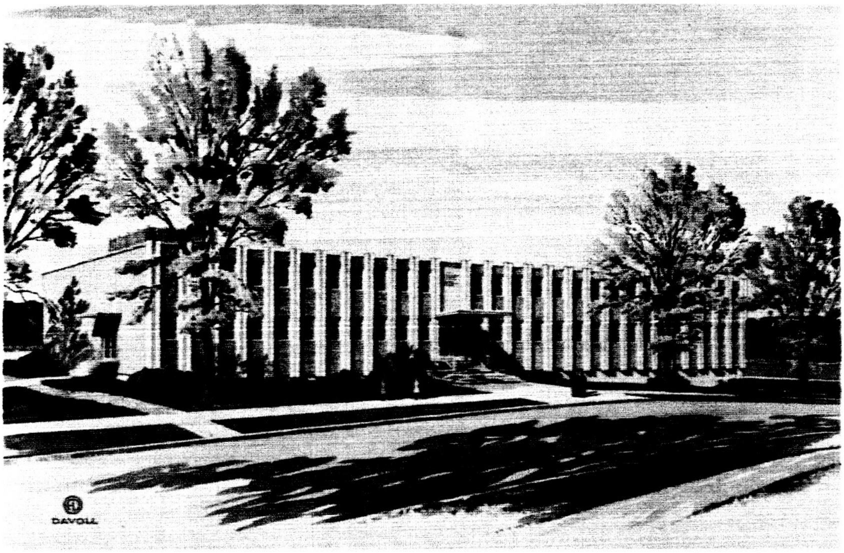

Figure 15.—Completed laboratory wing of propulsion building financed by NASA.

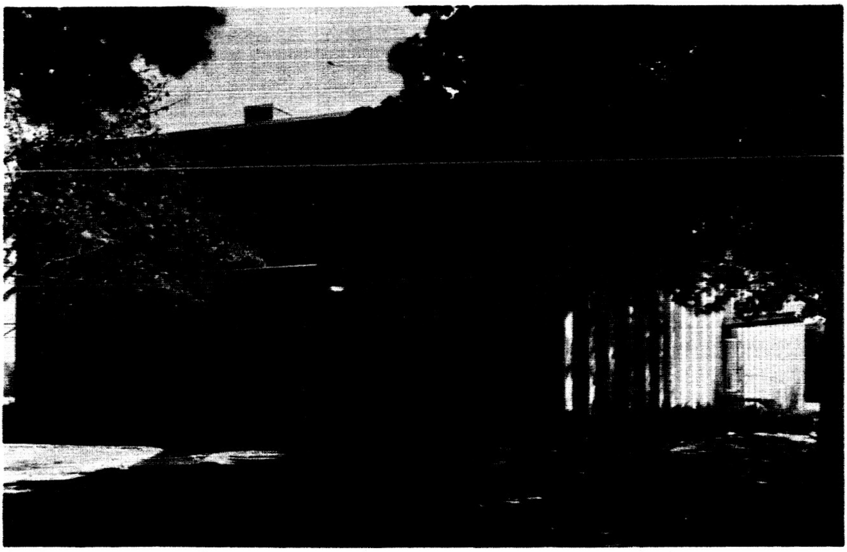

Figure 16.—Photograph of laboratory wing of aerospace propulsion building.

ton with the most extensive propulsion research and educational establishment in any university in the United States. Funds are still being accumulated for the remainder of the building.

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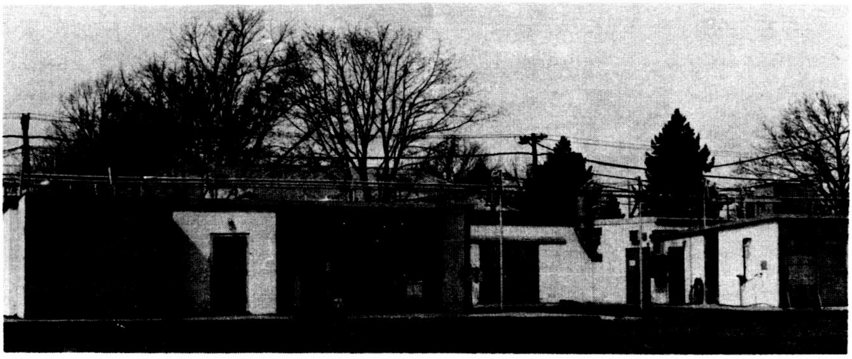

Figure 17.—Liquid-propellant rocket-engine test stands.

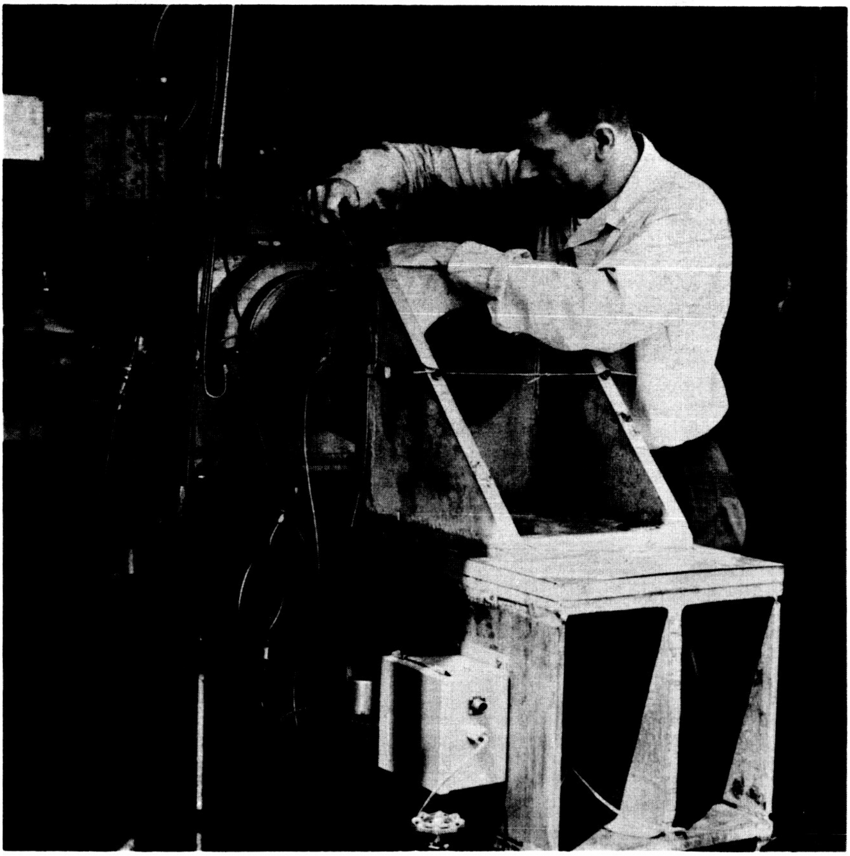

Figure 18.—Graduate student adjusting liquid rocket engine.

Figure 17 shows four rocket engine test stands being used for research on rocket combustion kinetics and combustion instability, a project supported by NASA. These experiments generally form the basis of graduate theses at the Master's and Ph. D. levels. Engine thrust magnitudes range up to about 10 000 pounds. A graduate student is shown in figure 18 making adjustments on a liquid-propellant rocket engine just before experimental firing. A firing of an experimental rocket engine to test theoretical predictions of rocket combustion instability is shown in figure 19. NASA has a direct interest in the problem of combustion instability of liquid-propellant rocket engines. It is safe to say that almost every liquid-propellant engine under development for the Apollo project has been troubled by combustion instability at some stage of its evolution.

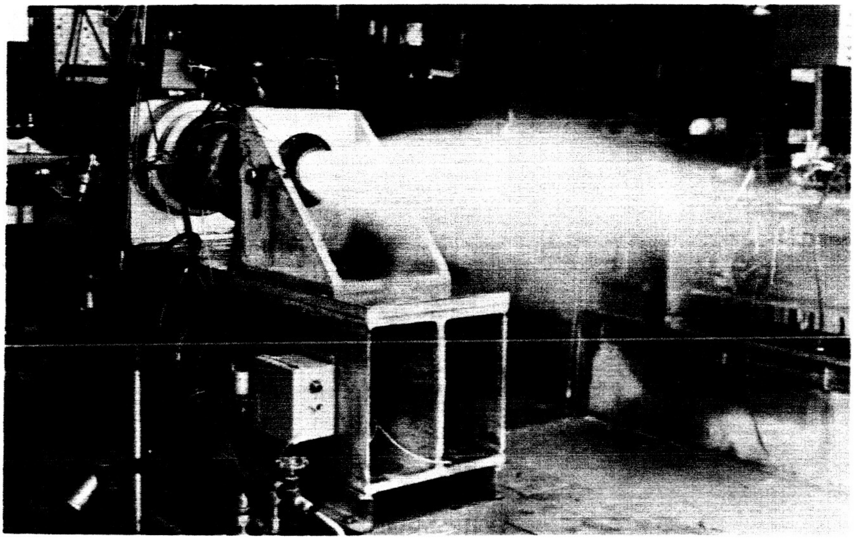

Figure 19.—Firing test in liquid-rocket combustion-instability research.

Figure 20 illustrates a piece of equipment used to study the basic combustion mechanism that drives an unstable solid-propellant rocket engine. The T-tube solid-propellant rocket motor has been found to oscillate in pressure during firing at a frequency corresponding to the closed organ pipe. The oscillating pressure field thus created acts on the burning test propellant at the left end to cause oscillatory burning. The nature of this oscillatory burning is the object of this research. This work is being performed by a student who is a candidate for the Ph. D. degree. Figure 21 shows the T-tube motor mounted on a firing stand directed upward and the graduate student connecting the ignition system just before the firing test. A broader

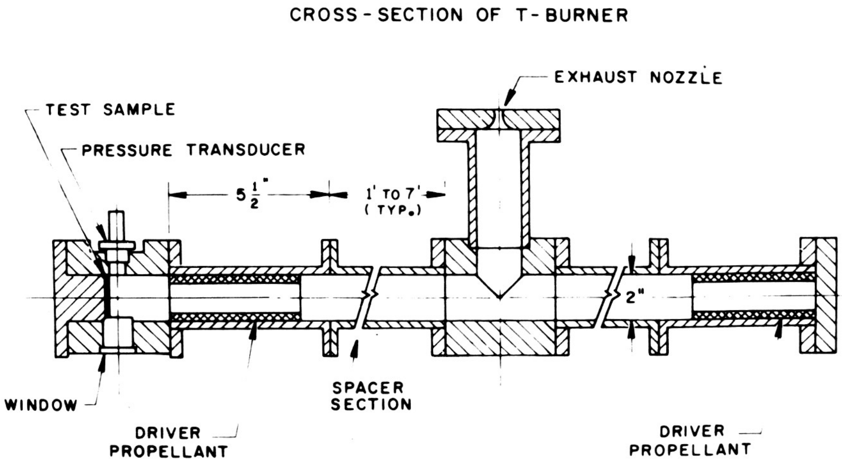

Figure 20.—Cross section of T-tube solid-propellant rocket motor for instability research.

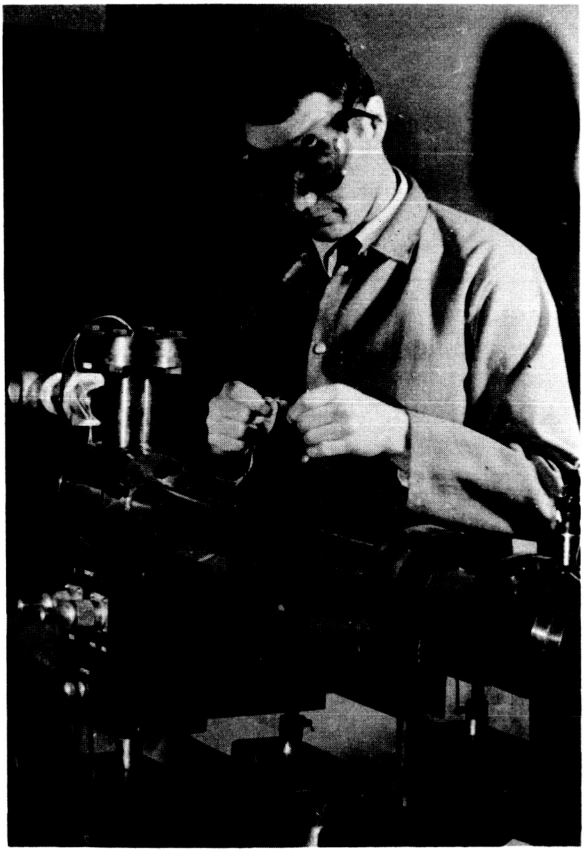

Figure 21.—Graduate student connecting igniter to T-tube rocket motor.

view of the T-tube motor mounted on the test stand is shown in figure 22. At the end of the motor in the foreground one can see the test section where the experimental propellant sample is mounted. The oscillatory flame from this propellant is recorded by a 5000-frame-per-second camera and simultaneously by a radiometer that measures the fluctuating luminosity of the flame. The fluctuating luminosity and the wave structure seen by the fast camera can be related to theoretical parameters involved in nonsteady combustion of solid propellants. (This project is supported by OSR, but some aspects are financed by NASA.)

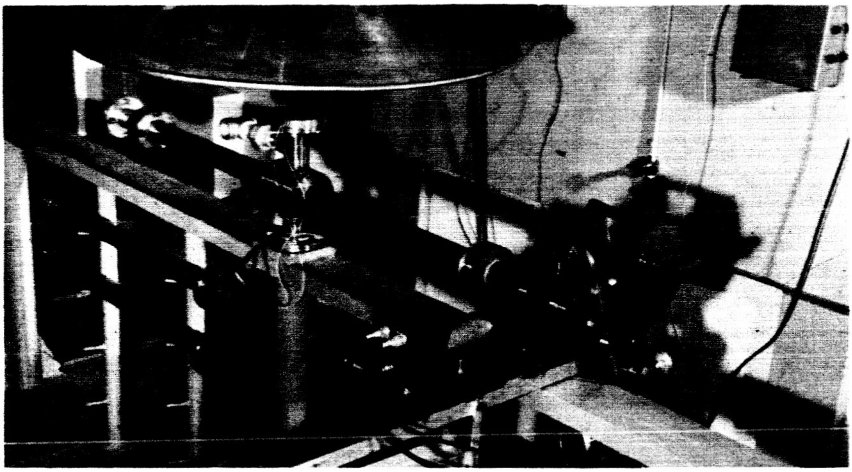

Figure 22.—T-tube motor ready for firing.

Figure 23 is an exterior view of the test cell for firing experimental solid-propellant rocket engines. Observe that it is totally enclosed by reinforced concrete walls, except for protected safety pressure release panels visible in the lower part of the concrete wall. The curved ducts on the roof conduct the jet gases out of the building into the atmosphere. The test cell has proved to be quite safe for operation in the Center where many other laboratories and classrooms exist. The building seen in figure 24 is the solid-propellant processing laboratory, in which students and technicians make experimental quantities of solid propellants for research on combustion. Many compositions have been made, including those based on nitrate esters and those based on ammonium perchlorate as oxidizers. (This processing laboratory, equipped with the finest of processing apparatus, was financed by a grant from the Advanced Research Projects Agency of the Department of Defense.)

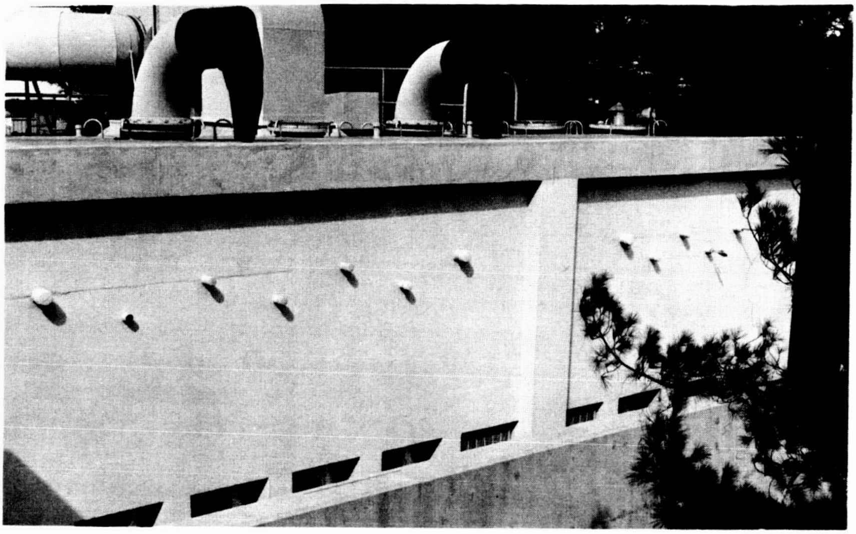

Figure 23.—Exterior view of solid-rocket-combustion test cell.

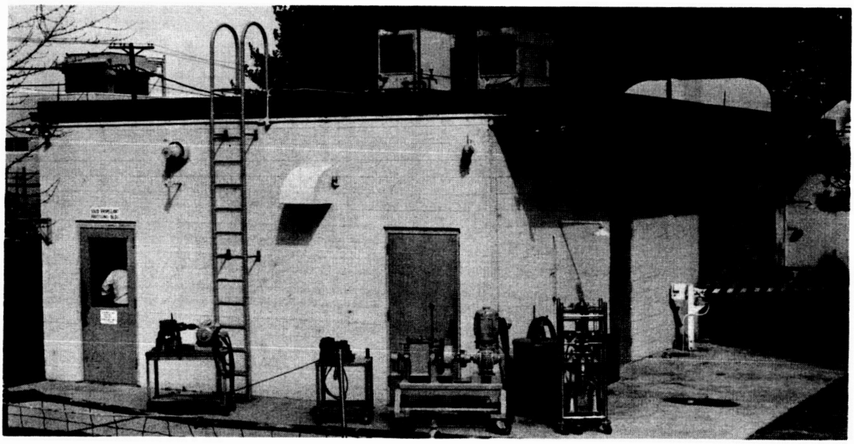

Figure 24.—Solid-propellant processing laboratory.

In addition to those researches that involve static test firings of rocket engines, the basic aspects of various propulsion systems are studied by graduate students in a wide range of experiments focused on particular phenomena. The following photographs provide a sample of the kinds of researches in which such students are involved.

Shown in figure 25 is a shock tube designed to study rapid ignition of a solid propellant when it is exposed suddenly to the hot gas created in the shock tube by the passage of the shock wave. The 18-foot long, 1.4-inch-diameter tube is designed to provide instantaneous gas

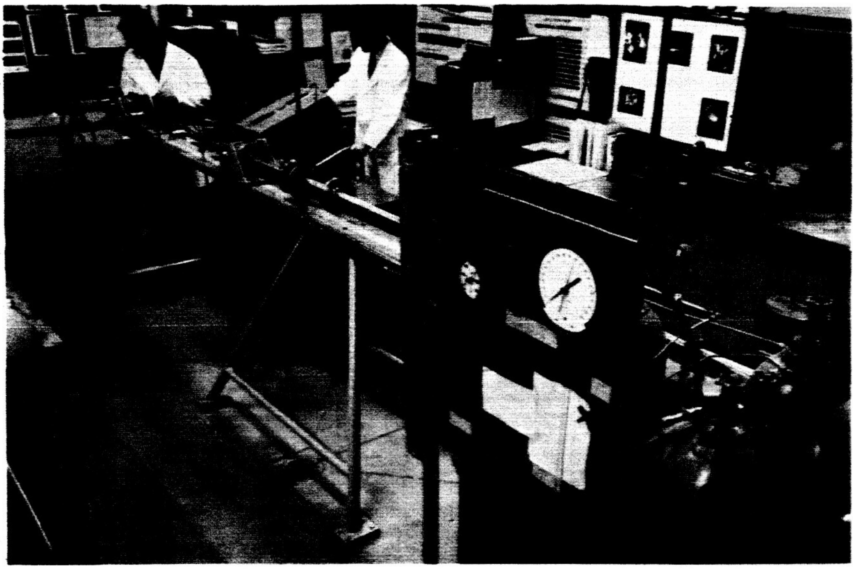

Figure 25.—Shock tube for solid-propellant ignition research.

pressures up to 50 atmospheres and gas temperatures up to 1000° C, an ideal situation for ignition that lends itself to theoretical analysis. The object of the experiments is to measure the ignition delay as it is affected by pressure of the igniting gas, the composition of the gas, and other physical and chemical variables. These effects are then studied for their implications as to the fundamental mechanism of ignition and compared with theories of ignition. Questions of ignition and combustion are of particular interest at low pressures, in the range applicable to solid rocket engines designed for upper stages of boosters or for spacecraft. The problems are significant also for large solid-propellant boosters. (This project is supported by OSR, but some aspects are financed by NASA.)

Another research area of importance in NASA's propulsion development program is that of the combustion of metals in gaseous atmospheres approximating the flame gas in a rocket motor. Light metals added to a rocket propellant are capable thermodynamically of raising the specific impulse to an important extent, but in practice there is frequently a substantial deficit in the delivered specific impulse of such mixtures. This disturbing deficit has focused attention on the mechanism and kinetic rate of combustion of metals such as aluminum, lithium, beryllium, etc.

Figure 26 shows a student observing the burning of an aluminum wire in a controlled atmosphere containing oxygen at subatmospheric pressure. Figures 27 and 28 are interesting photographs of the reac-

Figure 26.—Combustion of aluminum being observed by graduate student.

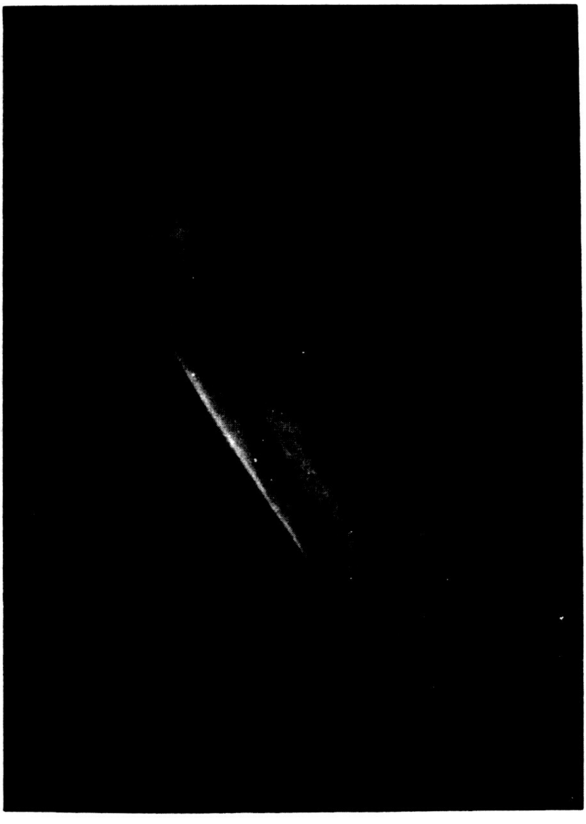

Figure 27.—Flame of aluminum burning in 50% CO_2—50% Ar at 50 mm Hg.

Figure 28.—Flame of aluminum burning in 80% H_2O—20% Ar at 60 mm Hg.

tion zone of aluminum burning, first, in an asmosphere of carbon dioxide and argon, and second, in an atmosphere of water vapor and argon. The most striking feature is the gaseous flame, showing that aluminum burns with a diffusion flame like that of a kerosene droplet in air. This identification of the structure of such flames has led to a theoretical treatment of the rate of burning of metals in this class, with considerable success. Other metals, and other oxidizing gases can be selected that show deviations from this simple structure, involving the formation of firm oxide coatings, etc. Inefficiencies have been correlated with some of these different structures.

As a final example of fundamental researches in propulsion phenomena, figures 29 to 33 show an experiment on the structure and propagation dynamics of a plasma wave created by an electrical pulse discharge and accelerated by its own magnetic field. Various plasma engine configurations based on this general principle are under development in the industry, but in general, little is known about the factors that govern the mass specific impulse or the energy utilization efficiency, two very important performance factors that will determine whether such engines will ever be used in interplanetary spacecraft.

Figure 29 shows a Ph. D. candidate making adjustments on a cylindrical discharge chamber energized by a pulse line containing

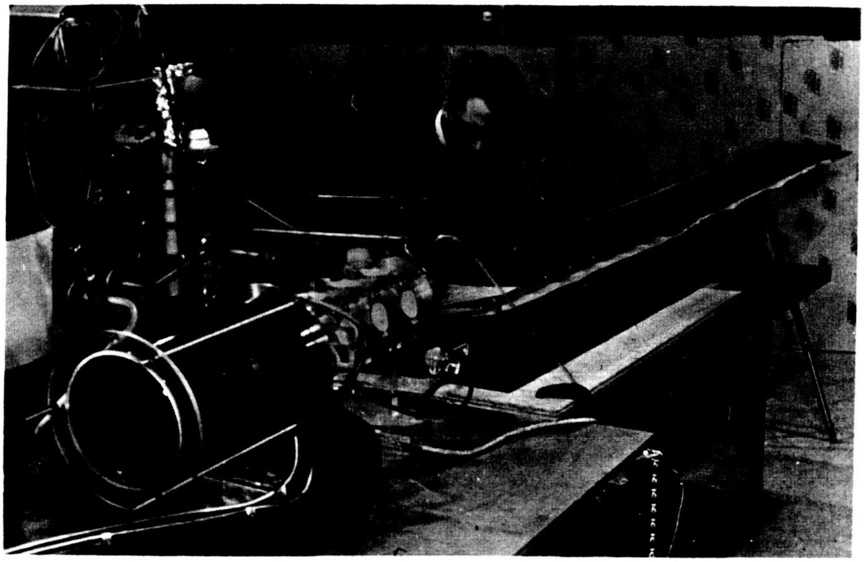

Figure 29.—Graduate student adjusting electrical discharge system of plasma pulse engine.

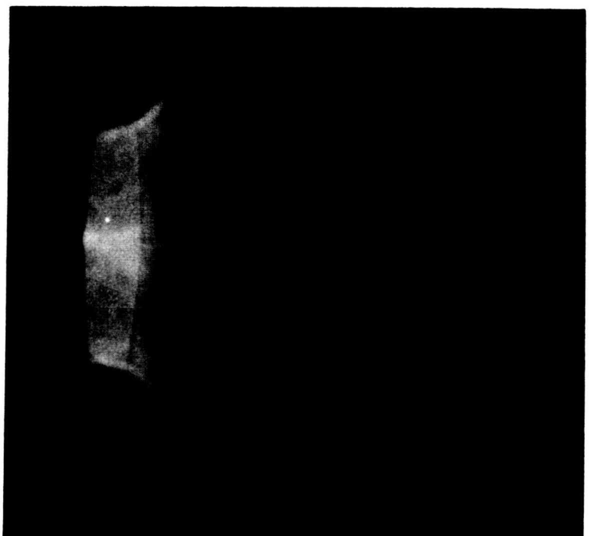

Figure 30.—Kerr cell photo of plasma wave 1.5 microseconds after inception.

twenty 2.5-microfarad condensers charged to 10 kilovolts. The current in the discharge is designed to reach a steady value of 200 000 amperes for about 5 microseconds. The pinched plasma exhausts axially (as seen in the sequence of figs. 30 to 33) with a velocity of about 40 000 meters per second (specific impulse of 4000 sec). The

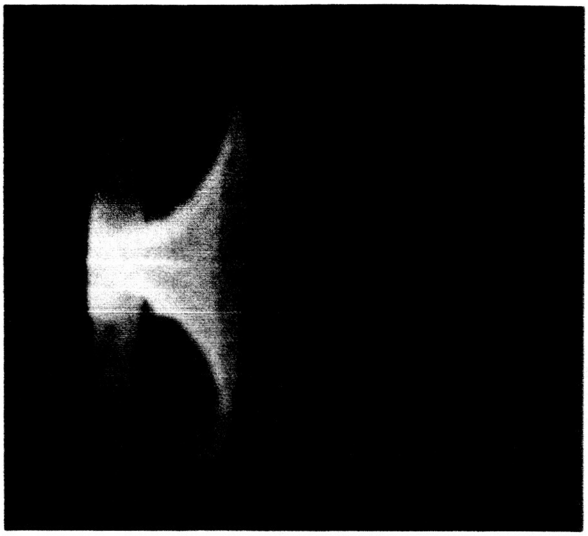

Figure 31.—Plasma wave after 2.2 microseconds.

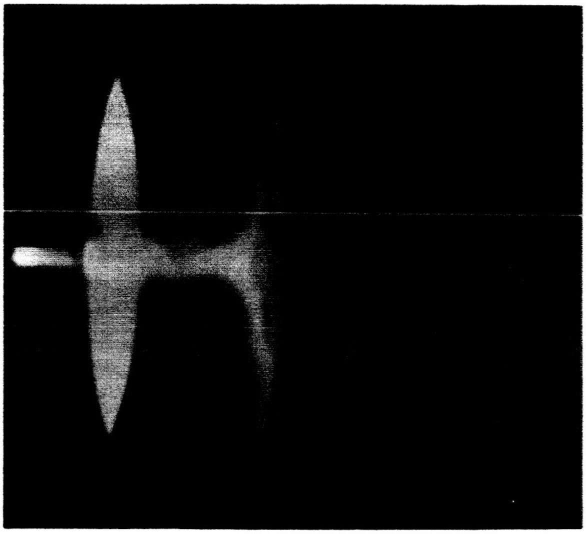

Figure 32.—Plasma wave after 2.7 microseconds.

cylindrical column of plasma is about 4 inches in diameter. Diagnostic measurements include Kerr cell photography (10^{-7} to 10^{-8} sec), microwave transmission, ionization probes, spectroscopy, magnetometer surveys, etc.

All these researches, and many others not shown, were conceived in support of NASA's long range objectives, as well as those of our Department of Defense sponsors in aerospace propulsion. At the same time they represent a broad range of masters and doctoral thesis material for the 35 graduate students majoring in aerospace propulsion.

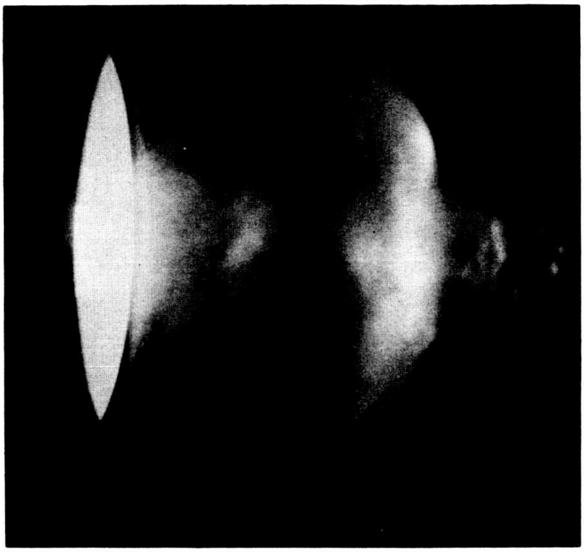

Figure 33.—Plasma wave after 6.0 microseconds.

The selection of a topic for a graduate thesis is based on at least two criteria, the importance of the ultimate goal for the future of astronautics, and the magnitude of the challenge in terms of the scientific depth of the problem. One test of satisfactory accomplishment is the acceptance of the resulting paper for publication in an archive journal.

In closing this discussion of NASA-sponsored researches at Princeton, it can be mentioned that NASA support is received in other areas of the University in connection with such space-oriented topics as lunar physics (Geology Department) and the effect of the space environment on life processes (Biology Department).

Princeton has not established a space sciences center as an organizational entity apart from its normal academic departments, but there is no doubt that NASA's objectives are served quite effectively, as previously described, by the system of direct project grants made to various departments in response to the academic and scholarly research interests of the faculty.

Futhermore, the NASA objective of encouraging university people to attack space problems through multidisciplinary approaches does not necessarily require an extradepartmental structure on the campus in the form of a space center. Multidisciplinary thinking is the element that has to be encouraged, not only for space problems, but for other problems as well, and this can be achieved by proper attention to the makeup of the curriculum and to the choice of thesis objectives. Like all problems of education, it is the faculty and not necessarily the organization that counts.

NASA SUPPORT OF GRADUATE EDUCATION IN SPACE SCIENCES AND IN ASTRONAUTICS

The last item of NASA support in Princeton that will be described here, but the one that is most firmly directed at the objective in the National Aeronautics and Space Act that calls for "the preservation of the role of the United States as a leader in aeronautical and space technology," is NASA's support of postgraduate traineeships and curriculum development.

Traineeship grants (i.e., graduate fellowships) are currently supporting 24 graduate students in various fields, including astrophysics, gas dynamics, aerospace propulsion, as well as others. Supplemental funds granted to the University in support of this expansion of the student body in space-connected fields have been used to finance an enrichment of the curriculum in astrophysics and in aerospace engineering.

Taken in its entirety, the stimulus given to the University and its proper educational mission through this partnership with NASA is great, indeed. It covers not only the NASA Traineeships and the NASA-financed curriculum expansion. It covers in reality all the thesis researches made possible by assistantships for students on research grants; it covers the enrichment of the University environment through the research activity of the faculty; and it covers the expansion of the faculty in space-oriented areas made possible by these sponsored activities. It is our belief that, in return for this sponsorship, the University is contributing strongly to the objectives of the Space Act described at the beginning of this paper. Thus, the NASA-University partnership is proceeding in a fruitful manner.

N66-12437

Institute for Direct Energy Conversion

Manfred Altman

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The Institute for Direct Energy Conversion at the University of Pennsylvania is rather small and we do not as yet have any outstanding achievements to take credit for, but it occurs to me that maybe it is our unimportance which really makes us important. Not every university can have space centers and tremendous facilities, whereas there are many that could very well do what has been done at Pennsylvania and settle for something less than total dedication to the space effort.

Perhaps it would be helpful to describe what was behind this institute, how it came into being, what its basic justification is, and then how our expectations for this institute have actually materialized.

I think that the area of direct energy conversion can be compared to what happened in nuclear engineering not so very long ago. There is almost a one-to-one correspondence in what happened. At one time the physicists had made their contributions as far as nuclear reactors were concerned, but it wasn't until the engineer learned the business of physics and became knowledgeable enough so that he could make contributions that major advances were made. So I foresee that the same sort of thing is going to happen in the area of direct energy conversion. Take the engineer working on thermoelectric generators for instance. It has been my experience that very few engineers have any knowledge of electrons, and I think this is the sort of thing which is definitely handicapping progress in the field of direct energy conversion. A personal experience relates to why this institute came into being. At one time I found myself at the Knolls Atomic Power Laboratories of the General Electric Company trying to help design a submarine nuclear reactor. At that time we had a tidy organization. We had a physics group, we had a heat transfer group, and we had a mechanical design group. The physics group would decide on what they needed to have a small compact nuclear reactor and to have it go critical. They then turned it over to my group; we looked at it and said, "We're sure it will work, but we don't know how to get the heat out of it." So back to the physics group it went and eventually we evolved a reactor which would certainly go critical and we thought we knew how to get the heat out of it; so we turned it over to our mechanical designers.

They, in turn, said, "This is all very wonderful; you know how to get the heat out, but we don't know how to build it." So back to physics it went, back to heat transfer it went, and so on. Finally, at Hyman Rickover's direction, a physicist and I were told not to emerge from our room until we had a design that would work. I assure you that not very many days went by before I had taught the physicist what he needed to know about heat transfer and he had taught me enough to give me an understanding of how one goes about a "physics design." When we emerged from this room we knew very well how to go about designing this reactor. I have never forgotten this lesson, because it pointed out to me again that we are rapidly approaching a state where the lack of communications is so acute that something simply must be done about it. Also, when I looked at the products we got from our universities and observed how carefully they had been trained in various disciplines and how carefully they had been kept away from related disciplines, it became quite clear that there was something very unsatisfactory about this.

I noticed this particularly in my last assignment in which I was concerned with space power planning. I found that the electrochemist was convinced that he had absolutely nothing in common with the plasma physicist, and if you tried to take a man who worked on thermoelectricity and asked him a question about photovoltaics, he wouldn't even listen to you. So clearly here was an area, which was becoming more and more important, definitely handicapped by the lack of engineers who had absorbed enough of related disciplines in science to do a good job.

At the University of Pennsylvania we eventually found some people who felt that some new ideas ought to be tried. So a group of us discussed the kind of organization we wanted. We wanted something which would keep us together and give us an identity, and we conceived the idea of an institute.

We decided that the primary purpose of the institute would be to provide engineering graduate students with an opportunity to obtain a *broad* background in the area of direct energy conversion. We decided that students would be required to meet the prerequisites of their *parent* departments for their doctoral degrees, but that students would perform their research in a common laboratory in order to stimulate their interest in other disciplines and to facilitate free communication. A limited number of postdoctoral researchers were provided for to facilitate continuity of research and to help the student researcher make the transition to experimental research. At Pennsylvania, experimental work had been neglected for quite a while, and pencil pushing had become very popular. Since we knew however what would happen to these engineers once they got into industry, namely that they would again be carefully kept away from laboratories, we thought that we should give them an opportunity to do some experimental work.

Another ground rule was that senior staff members were to be obtained from the permanent faculty. We weren't going to go out and recruit experts in direct energy conversion. We were much more interested in tapping the resources available at the University. We decided that all research engaged in by the doctoral candidates must be suitable for a thesis, thus limiting severely the kinds of problems that we were going to tackle. We decided that senior staff members were to act as thesis supervisors and were to have complete and sole power to choose suitable research topics, and again this put some limitations on what we were to do. We also decided that the senior staff was to develop and to present a course, or a sequence of courses, in the broad area of direct energy conversion. Our reasoning was as follows:

We tried to determine the sort of things we wanted our engineers to know. We wanted them to know thermodyamics, particularly irreversible thermodynamics; we wanted them to know solid state physics semiconducted theory, and then we could teach them about thermoelectrics and photovoltaics, namely solid state devices. We would then want them to know something about plasma physics and plasma diagnostics, and then teach them thermionics and magnetohydrodynamics. Of course, they would have to have some advanced fluid dynamics, and, of course, we would want them to know electrochemistry and electronics and high temperature technology and physical chemistry. All these subjects were available at the University. To take them, however, a student would have had to spend 10 years at the University. We realized then that we would somehow have to compress this knowledge, make a coherent whole out of it, and still not make it superficial. This was quite a challenge, but we decided that this would force our staff to work together, to get acquainted with one another, and with work going on in other departments.

We also made another critical decision. We decided that we weren't going to have the University of Pennsylvania be a branch of the Institute for Direct Energy Conversion. We therefore decided that we would like to stay small, and that we would try to produce something of the order of four Ph. D.'s a year. These then were the ground rules. Since we now knew what to do, the only remaining problem was to do it.

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So, we approached our administration. They said, "You tell us that this is important and we are in sympathy with you, but first show us that you can get some Government agency support. If you can do that, we really will believe that this is important and ought to be done." So we started seeking Government agency support. We managed to interest NASA's Office of Grants and Research Contracts in our plans and they supplied the financial support for the Institute.

Now that we had the money, we started planning for the future. A number of traps remained, however. We approached the University administration and said, "Well, can we do some long-range planning now?" The answer was, of course, "Well, not really; we can't make any long-range commitments to you since we don't know how long NASA will remain interested. After all, until we get some assurance that NASA will fund you for the next umpteen years we can't really make any commitments." Next, we talked to NASA and they said, "We gave you this money because we wanted to see how interested the University would be. We can't really promise you any long-range funding until we find out what the long-range plans of the University are."

The University of Pennsylvania is no different from any other university in that they all have some major problems. One of these problems is that we are teaching engineering which has become exceedingly hard to define.

We had, however, decided that the kind of people we wanted to turn out would be engineers and not scientists. One of the advantages at Penn is that we can tap a great many resources.

There is a great deal of basic scientific work going on and we also have a business school. The first thing we set out to do was to find out what basic engineering is. We talked to our industrial research colleagues who explained what they considered to be industrial laboratory type of experimentation and research. Then we talked to the staffs of our basic research departments; they explained what they considered to be basic research. When we superimposed these two we found that there was a perfect interface between basic research and industrial research; as far as basic engineering was concerned, there wasn't any. We came to the conclusion, then, that no matter what we did we would either offend the industrial researchers or the basic science researchers; however, we decided to move ahead cautiously.

In order to solve this problem we decided to set up the kind of organization which would have representatives from both industry and Government agencies and from university engineering and science. We established three major groups in the Institute. One is devoted to what we call plasma engineering, one is devoted to electrochemical engineering, and one is devoted to materials sciences. The materials group, for instance, engages in studies on thermal energy storage, high temperature thermoelectrics, and so on.

Each one of these groups has regular staff members which we borrow from their parent departments. After a professor has become interested in a certain problem and indicates a desire to work with one of our groups, we negotiate with the director of the school for a certain fraction of his time. We don't necessarily want permanent people in our various groups; we would like to attract people from chemistry, chemical engineering, or electrical engineering. Once they have made their contribution to a particular problem there is no reason why they shouldn't leave us again. We like the association with the Institute to be strictly voluntary.

Each one of these groups has a certain number of postdoctoral researchers in it; it also has technical people from industry in it, and this is how we manage to bridge the gap between industrial research and the basic engineering which we would like to do. I believe that this interaction between the two groups, with each giving the other ideas, has worked exceedingly well. We also routinely draw on various experts from Government laboratories to work with our groups. These groups meet about once a month and review progress. Our graduate students report to these groups on the progress they have made. We have found that having industrial researchers working with us in these groups has been of tremendous help in guiding graduate students. Besides supplying knowledge and guidance, they, on occasion, lend us equipment.

These groups are composed of representatives from totally different disciplines. For instance, we have discovered that electrochemists concerned with "double layer" use the same equations that plasma physicists use in describing sheath problems. So these two branches now have at least one project going in surface physics which will be just as useful to the electrochemist as it will be to those concerned with thermionic energy conversion.

The fact that we are still in existence today ought to be indication enough that this format for an institute has worked. There are still many problems.

For example, how do you convince a faculty member that he ought to take time out to learn? It is terribly difficult to explain to, for instance, a microbiologist that it would be advantageous if he would spend a year learning electrochemistry so that he could attack a problem such as a biological fuel cell. We have not had outstanding success along these lines. The problem is simply that researchers are expected to publish, and it has been so ingrained by this time, that if they have a choice of learning something new or of capitalizing on what they already know, by publishing several papers during this year, they will always choose the latter. We don't know yet what the cure for this is but we are working on it.

The interface between basic applied and industrial type research is a difficult to define problem area. An illustration of how this problem can be managed may help.

We have a rather important basic electrochemistry laboratory at the University of Pennsylvania under the direction of John Bockris. Some of our engineers became interested in microconvection phenomena within electrode pores and a dispute arose between the two groups as to whether the study of microconvection was engineering or basic electrochemistry. We explained that the only reason we are interested in microconvection as far as space applications are concerned is its effect on gravity—what happens in the zero-G field when this type of convection is missing. The work was arranged so that the electrochemistry laboratory would study the basic phenomenon of microconvection and the engineering staff would study the zero-G effects. As a result, the conflict was resolved.

Another difficulty is getting basic scientists to work on engineering problems. For example, we have a "Laboratory for Research into the Structure of Matter" with a number of good solid-state physicists. We wanted to interest them in high-temperature thermoelectrics or thin-film photovoltaics. We approached them by saying, "You have been studying the quantum mechanics of these films for several years now, and we know you have made a quantum mechanical study of transport phenomena. Here are some of the problems we have. Can't you give us a material which has a very high electrical conductivity and a very low thermal conductivity?" Although the scientist feels obligated to express his distaste with engineering problems, he may have done something that might be a clue, and with enough patience and encouragement, you may be able to interest him and to get his help. Then, sooner or later you may find someone in the metallurgy department who would like to make some of these materials, and a liaison can be established.

These are a few of our experiences in bringing about the type of an institute which offers all the advantages of identity and yet brings people together to work on interdisciplinary problem areas.

N66-12414

NASA-Supported Basic Research at the College of William and Mary

Robert T. Siegel

DEAN OF GRADUATE STUDIES

COLLEGE OF WILLIAM AND MARY

THE COLLEGE OF WILLIAM AND MARY is a well-known liberal-arts college and is the second oldest institution of higher education in the United States, having been chartered in 1693. On the campus of William and Mary there stands a building which was originally constructed with funds from the estate of Robert Boyle.

During colonial days, when Williamsburg was the capitol of the colony, the college was a center of intellectual activity for the entire colony. In 1789 the state capitol was moved to Richmond for military reasons, and the college has remained of modest size since that date. It is located on the peninsula between Richmond and Newport News, this peninsula being the same one which was the object of much struggle during the Civil War. In 1906 it became a state-supported institution and is at present entirely a publicly supported institution.

History is beginning to come full circle. Whereas civilization moved away from the college towards the end of the eighteenth century, it is now returning. The college is on the edge of the fastest growing metropolitan area of Virginia, the Tidewater area, having a population of a million and including the cities of Norfolk and Newport News. This population has doubled since 1945 and is expected to double again in something of the order of 15 years. In this area there is a great need for graduate education. The rate of production of Ph. D.'s for example, in Virginia is all too similar to that in most other southern states, with the notable exception of North Carolina. So during the last decade the college has initiated graduate programs in many of its departments. In this endeavor, the college has a solid undergraduate program in many disciplines of arts and science.

USE OF NASA MULTIDISCIPLINARY GRANT

The activities at the College of William and Mary related to a research program supported by a NASA multidisciplinary grant began a little over a year ago with the award of this grant. A portion of the funds available under this grant have been made available to the biology department, which has established the Laboratory of Population Ecology, which is involved in studying the physiological effects of biological and psychological stresses on small mammals. Particular attention has been placed on the rates of production of adrenalin and noradrenalin in small mammals, as a function of environment. This year the biology department is also receiving additional support from this grant for beginning investigations on radiation effects in certain biological systems.

Most of the funds available under this grant have been used to support activities within the physics department. For example, a quite excellent laboratory in visible and infrared spectroscopy, which is staffed by the school, has been equipped by means of funds from this grant as well as from other sources. There has been some support of plasma physics, particularly in investigations of the physics of Penning gages, and of transport theory studies for charged particle beams. This last work has again found independent support.

At William and Mary, an attempt has been made to concentrate support in a relatively few departments, one or two, which show particularly great need and, of course, promise in the eyes of the administrating committee. In an institution which is steadily evolving towards an increased role in graduate education, the use of all such multidisciplinary funds to support only one or two departments at a time has seemed wise.

A major portion of the funds available under this grant are used in the support of a large group engaged in study of high-energy physics. This is the first time that research in high-energy physics has been supported by NASA, and it is particularly significant that high-energy physics, which has been accused of being technologically useless, has found a very important use as far as NASA and space science is concerned. The reason for this is quite clear. Solar flare protons have a mean energy of 500 000 000 electron volts, and some of them extend up into the multi-BeV region. The radiation effects of such protons are largely unknown and extremely important in plans for interplanetary travel.

SPACE RADIATION EFFECTS LABORATORY

About 2 years ago NASA Langley Research Center began construction of a laboratory called the Space Radiation Effects Laboratory, which is about 10 miles from Langley Field and about 15 miles east of Williamsburg on the peninsula. Due to the foresight of NASA and the Langley Research Center, half of the time available for experimentation with the 600-MeV cyclotron at the laboratory, and the entire management and operation of this laboratory, have been assigned to three Virginia institutions, the College of William and Mary, the University of Virginia, and Virginia Polytechnic Institute. These institutions have formed the Virginia Associated Research Center, which will manage and operate the cyclotron. Approximately half of the accelerator time will be used for basic research studies, primarily in physics at first, by members of the three institutions and possibly members of other institutions in this region.

It is important to consider this accelerator installation in another context. The 600-MeV cyclotron is the only machine capable of producing unstable elementary particles, pions and muons, in a geographical region bounded on the north by Princeton, N.J., and on the west by Berkeley, Calif. A large part of the United States has not had available within reasonable traveling distance a facility at which physicists could do elementary-particle research. This accelerator will hopefully be an incentive for physicists throughout the Southeastern United States to begin work in this exciting field of research.

HIGH-ENERGY-PHYSICS GROUP

The College of William and Mary has attempted to answer the challenge afforded by the large accelerator by setting up a high-energy-physics group. (Actually, 600 MeV is so far below the present frontier of high-energy physics that work in this energy region is beginning to acquire a new name, intermediate-energy physics. This is the region which is bounded on the lower end by 100 MeV and nuclear physics, and on the upper end by 1 BeV and kaon physics.) At the college this group, which was formed and started activities about 16 months ago, presently consists of five faculty members, one Ph. D. research associate, and supporting personnel in the form of electronics technicians and machinists. At present nine graduate students in various stages of their studies are also supported as part of this activity.

Last year the college was authorized to award the Ph. D. in physics and also in marine science. This was the first time in the history of the institution that the doctorate degree has been authorized. The department of physics is quite large now, having 17 faculty members; it forms about one-quarter of the total staff and occupies one floor of the very elegant physics building completed last year.

When this group was formed, the cyclotron was at that time under construction. Now, synchrocyclotrons have been around for quite a long time. They were the first high-energy accelerators and they generally produce about 1 microampere of internal beam. The limit of experimentation possible with this beam intensity has been almost reached. Much attention has been directed towards improving cyclotrons throughout the world; thus, the group decided that its first activity, even before it had equipment for performing experiments, would be a conference on high-energy cyclotron improvement, which was held in February 1964 and attracted people from essentially every cyclotron laboratory in the world. At this conference, the high-energy-physics group at the college and everyone present became convinced that the internal beam of a cyclotron could be increased to 20 microamperes, with a modest expenditure of money. The reason for such certainty is that this has been done in one machine at Orsay, France, which has an internal radio-frequency structure of rather advanced, but reasonable, design. In addition, it is hoped that the internal beam of a cyclotron may eventually be increased to 100 microamperes.

From the research point of view, the interests of the high-energy group have concentrated in low-energy muon and pion physics. There is particular interest in the muon capture interaction, and while the Space Radiation Effects Laboratory is being completed, some work which had been started elsewhere by members of the group is being continued. Since this group was formed at William and Mary, it has therefore had two cyclotron runs at Carnegie Institute of Technology and completed a survey of the muon capture rate throughout the periodic table. Muon capture rates have been measured to the very high precision in about 50 elements of the periodic table, and for the first time evidences of nuclear structure effects in the muon capture interaction rates have been found.

Mentioned previously was the fact that one of the programs supported initially by the multidisciplinary grant was a program for the design of transport systems of charged particle beams. This program involves mainly the design of a muon channel, an array of 25 quadrupoles and a bending magnet, and also the construction of the test equipment for measuring the beam quality of pion and muon beams which will be transported from the cyclotron into the experimental area now under construction.

The conference led the group to consider what steps might be taken to prepare the cyclotron for further improvements. Once a cyclotron is built it is difficult to take it apart. There is a great deal of resistance to disassembling a machine on the part of all the physicists who want to use it and the engineers who are going to have to do the job, so it was felt that it would be desirable during the construction if some steps could be taken which might facilitate later improvements to the cyclotron. One of these steps was the correction of the magnetic field of the cyclotron to a high precision. A cyclotron is normally thought of as having a cylindrically symmetric field, which should result from the shape of the pole tips. There is, however, a basic lack of symmetry in the two yoke members which come down beside the pole pieces, and this condition leads to azimuthal variations, which in this particular machine design were quite large. Therefore, the problem was looked at carefully, and a suggestion was made to Langley Research Center that it would be desirable to shim or correct the magnetic field so that the azimuthal symmetry was at least one part in 10^4 or about 2 gauss out of 20 000 gauss. This shimming was to be accomplished by drilling about 1000 holes, of 2-inch diameter and varying up to 0.75 inch in depth, in the lower pole tip of the magnet. After due consideration, Langley agreed to undertake the job of drilling the magnet. With the cooperation of physicists from the other two institutional members of the Virginia Associated Research Center, the magnet-pole-tip drilling program was executed this last winter. This program involved quite a considerable computational and engineering effort on the part of Langley. The mechanical part of the work was completed in only a few weeks. The measurements and slight corrections have taken a total of 10 weeks, during which time a great deal of detailed information was gained on the properties of the magnetic field.

In addition to such activities, the high-energy group at William and Mary has engaged in the development of instrumentation, with particular attention to liquid-helium scintillators. That all the noble liquids and noble gases scintillate quite efficiently is perhaps not generally realized. However, very little is known about the details of the scintillation processes. In liquid helium, for example, the identity of the atomic or molecular entities which are emitting light are not known. The wavelength of the radiation emitted is not known, although it is very short, on the order of a 1000 angstroms, requiring wave-shifting fluorescence techniques in order to bring the radiation up into the visible range. At William and Mary the work on liquid-helium counters has concentrated on improved resolution in large detectors. The best resolution attained has been under 10 percent (FWHM) on 5-MeV alpha particles, and a counter with sensitive volume 6 inches in diameter and 6 inches high has just been completed.

Figure 1 is a photograph of another type of scintillation counter under development. This counter is of a rather unusual design and for a while it seemed topologically impossible to execute. It is designed to increase the timing accuracy for a charged particle beam of a large area. This particular one is 8 inches by 8 inches and should improve the accuracy with which such particle beams of such area can be

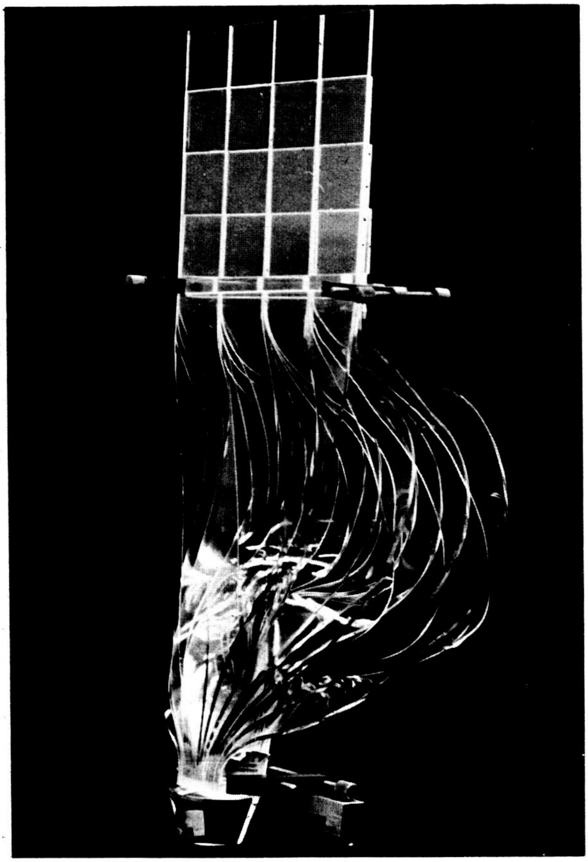

Figure 1.—Isochronous scintillation counter.

timed, to about 0.5 nanosecond. (The other activities of the group have not resulted in apparatus as photogenic as this scintillation counter.)

The activities of this group, then, include instrumentation and preparation of experiments for cyclotron research. It has sponsored one conference and will soon have another, this time on intermediate-energy physics itself. It has studied cyclotron beam dynamics and the development of transport apparatus for use at the Space Radiation Effects Laboratory, and has also aided in some work on the cyclotron itself.

CONCLUDING REMARKS

In summary, the impact of the following factors:

(1) The support by the NASA Office of Grants and Research Contracts for space-related activities, including for the first time high-energy physics at the College of William and Mary, through a multidisciplinary grant, and

(2) The opportunity created by the foresight of the Langley Research Center for all educational institutions in this region to participate in the research activities at a large accelerator installation,

has resulted in an increased rate of evolution by an honored liberal-arts college towards a modern university.

Multidisciplinary Research at Washington University

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ALTHOUGH THIS PAPER is under the general heading of research, no review of Washington University's role in the NASA University program would be complete without a discussion of the NASA participation in the construction of the new Arthur Holly Compton Laboratory of Physics, now more than half completed on the campus. Whereas building construction is not research in a true scientific sense, modern laboratory facilities are indispensable to thriving university research in the physical sciences. The Department of Physics has numerous research activities of considerable relevance to space science. Yet the department is now crowded into a structure completed in 1934 and designed for a department of perhaps one-half its present size.

The new laboratory is T-shaped and the major portion, which corresponds to the horizontal bar of the letter "T", is the research wing, five stories high. The stem of the "T" joins onto the present Wayman Crow Laboratory of Physics, a building of about 42 000 square feet. The Compton Laboratory will have over 60 000 square feet, giving the physics department, by next fall, well over 100 000 square feet in which to carry on its researches. NASA has, in effect, provided the upper floors of the research wing of the Arthur Holly Compton Laboratory.

The laboratory commemorates Arthur Holly Compton, not so much as the chancellor of Washington University, which he was nearly a decade after World War II, but as professor of physics during the period 1920 to 1923. In a building now occupied by the Psychology Department, he discovered the Compton effect in 1922. In what would now be considered a faculty raid, he was called to Chicago in 1923.

The NASA participation in this structure is approximately one-third of the cost of the structure; another one-sixth comes from the National Science Foundation; and the remaining half from private sources. This Compton Laboratory is the first in a series of major laboratory facilities that are projected for Washington University. Construction has just begun on a new Monsanto Laboratory of the Life Sciences, which is the first stage of a two-stage program for a much larger program in life sciences. Thereafter, plans have been made to add new laboratories for Chemistry, Engineering, and the Earth Sciences and to bring modern standards to near-obsolescent facilities in these sciences. Since there are NASA trainees in all of these fields, it will be of great benefit to them to get these new buildings underway.

To turn from research facilities to space science research on the campus, this brief report cannot possibly deal adequately with even the NASA-supported research alone. Therefore, an attempt to cover research of relevance to space science and exploration, which happens to be supported by other agencies on the campus, will not be made.

The longest standing NASA grant at Washington University is an astrophysical investigation of the primary cosmic radiation. Research was carried out during the summer of 1962, in the region of the South African magnetic anomaly, along with simultaneous balloon flights from Northfield, Minnesota. Analysis of these emulsions is still continuing. To date, an energy spectrum (in the region of kinetic energies from 2 to 10 GeV per nucleon, for alpha-particles) has been obtained, as well as considerable other information on the variation of geomagnetic cutoff energy with arrival direction in the east-west plane. Further work will involve the charge distribution among primary particles having a Z of about 6 or greater.

In addition, under this grant a spark-chamber-emulsion assembly is nearing completion. Two spark chambers will be triggered by a scintillation counter telescope. This apparatus is already under test and is expected to fly, in test flights at least, within 1 month or 6 weeks.

The foregoing is an example of *project* research. The program of primary concern is that under the NASA Multidisciplinary Research Grant. This grant is administered within the university by the provost, with the advice on policy matters of a faculty council on space sciences. There are features of the administration of the grant that merit comment before some of the research carried out during the first year of the grant is described. Everyone is familar with the project system of research support in universities, under which it is probably unanimously agreed that U.S. science has flourished during the past 15 years as never before.

By the project system is meant, of course, support whereby the specific research proposal to potential granting agencies is outlined along with a detailed budget. This is followed by a scientific review as well as the financial and business negotiation of the grant by NASA officials, in this case, and those at the university. Even under the most favorable conditions, and for any agency, such a project normally will require *at least* 6 months from the inception of the research idea to the existence of a research budget account at the university from which the professor can draw.

For the well-established professor with other on-going research programs, this gestation period of 6 months to 1 year for a research grant may be perfectly acceptable, provided that the requirements for this new research idea are reasonably closely related to the facilities for his on-going research. But if the new idea is a radical departure from his existing line of research, requiring very different apparatus or possibly new technicians with different special competences, the gestation period for a grant can be annoyingly long, even if the sponsoring agency has an adequate budget, which has not been generally the case for the physical sciences in the U.S. during the past 2 years.

Incidently, the Physics Survey Committee of the National Academy of Science and National Research Council, which is like a parallel committee for chemistry, is engaged in an exhaustive survey of the needs of physics for the next few years. In examining what has happened in the recent past it was found that, in the physical sciences, that is, physics, chemistry, and basic engineering, research funds have essentially been level for the fiscal years 1963, 1964, and 1965, particularly in the universities. With the normal inflation in research costs considered, it is apparent that level research funds correspond in reality to a decline. This is a serious problem, so that the project system, which at best already has a certain built-in time constant, has a far greater problem now that there are inadequate financial resources.

For the newly recruited faculty member, who may have completed his activities elsewhere just in time to arrive on campus in the fall, the first year in his new faculty position is all too often one of anxiety and frustration as he impatiently attempts to get his research up to full momentum, while writing research proposals, awaiting agency review, and hoping that the agencies have free funds (as they have not, e.g., in chemistry and physics in recent years). If the result of this situation is even a temporary research hiatus for the young faculty scientist at a time when he is full of research ideas and is at the peak of his physical and mental vigor to explore them, it is tragic for him, for his students, for the university, and for the Nation's science effort. It is in helping to avoid such tragedies, at least where the space sciences are involved, that the NASA Multidisciplinary Grant at Washington University has been most remarkable. It also has aided materially in a couple of instances in allowing established scientists to move rapidly in new directions.

In the administration of this particular grant I have found it necessary to rely rather heavily on my background in physics and chemical physics, along with help from the assistant provost, who is trained in engineering and who is director of the Washington University Computing Facilities. Originally, it was hoped that the Faculty Council on Space Sciences would select the internal research proposals for funding. This turned out not to be feasible, at least in a medium-sized institution such as ours, because the most informed and competent faculty members in the sciences relevant to space, who were necessarily those to serve on the council, also in many instances had vested interests in the requests for funds. As a consequence, the Council decided that the selection of proposals to be funded would have to be made in the provost's office. Actually, this has worked reasonably well because of the policies set forth by the council.

As an illustration of policy decisions made, the shortage of research funds in the physical sciences, coupled with the fact that, by and large, the health-related and biological sciences are not suffering a similar shortage of research funds for project support, led to the decision that the multidisciplinary grant would be limited to the physical sciences and engineering, although originally it was hoped biological work would be included.

Even with that limitation there were, at the first award point immediately after the grant, \$700 000 in requests for support from \$300 000 of funds. Of those, \$600 000 were worthwhile projects, so to speak, eminently worthy of support. By now, the so-called "proposal pressure" has probably grown so that it is almost double what it was then, still with the same amount of funds.

For making these decisions as to who receives support, there is no alternative in an institution of this size to a decision by scientist members of the administration who are not themselves competitors for the research funds which they, in effect, are dispensing. Fortunately, there was clear agreement on policy, which gave priority to establishing new faculty members in their research or to shifts in research directions. When combined with criteria of relevance to space sciences, these policies led to reasonably clear cut and relatively uncontested decisions.

In the Department of Chemistry, research on the reaction of hot silicon radicals was begun by the investigator during his first year on the Washington University faculty after completing his postdoctoral research at Caltech. This research was proposed as a study of the attack on other molecules of the energetic radicals that recoil from the sites of nuclear reactions induced by bombardment with energetic particles. There is an evident relevance to space research through increased knowledge of the radiation damage processes that occur when space vehicles are exposed to radiation and increased knowledge of the chemical reactivity of radicals typical of those prominent in the interplanetary environment. With the emphasis on hot silicon radicals, there is obvious fundamental chemical interest centering on the relation of silicon chemistry to carbon chemistry. There are also deep questions relating to possible biogenesis of silicon-based life on distant planets.

Study of the chemical reactions of recoil silicon atoms in the gas phase is well underway. Preliminary efforts have centered on the systems silicon (Si) + dimethylsilane ($(CH3)_2SiH_2$), and Si + methane (CH_4). In the former, Si^{31} was produced by the $Si^{30}(n,y)$ Si^{31} nuclear reaction by using thermal neutrons from an atomic pile; in the latter, the $P^{31}(n,p)Si^{31}$ reaction with fast neutrons was employed as the silicon source. Significant evidence has already been found for hydrogen abstraction by silicon atoms, leaving radicals of carbon-hydrogen composition.

For some time in the Department of Earth Sciences, two professors have been involved in paleomagnetic studies. They are investigating Precambrian rocks of the St. Francois mountains in Missouri. They find the Precambrian igneous rocks to be extremely stable magnetically. The north pole of the geomagnetic field that magnetized these rocks was located in the Pacific Ocean in the vicinity of the Christmas Islands (near the equator). These results support hypotheses that the magnetic pole has shifted and/or that continents have drifted during geologic time.

One professor is also engaged in an extensive paleomagnetic program in cooperation with Japanese scientists in Taiwan, Korea, and the Philippines. In this Pacific program are observations of apparent polarity reversals, suggesting that the Earth's geomagnetic field has reversed polarity with a period of about 1 million years.

The recent geophysical studies begun under the NASA Grant have as their purpose study of the transient electrical pulse behavior and variation of other electrical properties of certain rock types as a function of the frequency of the inducing field. These studies are prerequisite to the development of new or modified geophysical techniques that may be amenable to shallow planetary exploration.

Samples of St. Francois Mountain igneous rocks and of Bonne Terre dolomites from Missouri, along with tektite samples from Georgia have been collected. The future plans are to try to relate the magnetic and electrical properties of these rocks.

A professor who has joined the faculty of the Department of Earth Sciences just this year after completing his doctorate at the University of California in La Jolla is establishing his researches in the use of nondestructive chemical analytical procedures for determining the

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constituents of rock and mineral systems. The NASA grant has enabled him to begin instrumentation for X-ray fluorescent spectroscopy pending decisions on project support for his work.

Two professors from the Department of Physics working on cryogenic detectors are investigating certain solid-state devices with a view to their use as thermometers, phonon detectors, and pressure transducers in the temperature range between 0.01° K and 1°K. These detectors are needed in fundamental experiments on properties of solid materials of interest in the space program and wherever fast and very sensitive heat detectors are required. (There is also the possibility that such detectors might be directly useful in certain kinds of highly sophisticated space vehicle instrumentation.)

The cryogenic system for achieving temperatures in the 0.1° K range has been assembled and tested. A superconductor solenoid is used to achieve these temperatures by adiabatic demagnetization. It has been learned in this research that the heat detectors, which employ thin films of vacuum-deposited carbon, can be considerably increased in sensitivity by introducing certain metal impurities into the carbon.

Also in the Department of Physics, a research project on noise reduction in lasers and masers has as its goal the understanding of noise effects in laser oscillators and amplifiers; in particular it investigates the feasibility of altering spontaneous-emission noise by initial state selection, which is theoretically possible according to quantum electrodynamics.

Apparatus has been built and assembled. The preliminary noise experiment is a study of the sources of fluctuation in the output of a commercial helium-neon laser with a view to eliminating and understanding the statistical properties of the noise sources. With available photocells and low-noise amplifiers, it appears feasible to the investigator to measure fluctuations as low as 150 decibels below the level of oscillation. (This investigator is a theorist with, however, much practical background, who is taking a somewhat experimental turn in this research.)

Research on momentum and heat-transfer characteristics of circular, turbulent, impinging jets with large temperature gradients in the Department of Chemical Engineering begun under the multidisciplinary grant, now has project support. There is direct application to several space-related problems. One is the question of heat transfer from a positioning-rocket exhaust impinging on the surface of a space vehicle in rendezvous maneuvers. Another important application is in the testing of heat-shield materials.

The project investigates analytically and experimentally the problem of the fluid mechanical and heat-transfer characteristics of compressible, impinging, turbulent jets. The project to date has concentrated on investigating the applicability of available analytical techniques to the problem and on the design and construction of the experimental equipment.

On the basis of a survey of previous work on the incompressible, impinging jet and a consideration of pertinent mathematical techniques, it has been concluded that, for analytical purposes, it will be necessary to consider the momentum and energy flux field of the jet in three separate (but, of course, interconnecting) parts. The first part is the free-jet region, where the influence of the impingement region on the flow and enthalpy field is negligible. Some experimental work has been done previously on compressible free jets. The analytical treatment of this region, however, is complicated by the fact that the velocity and temperature profiles in the free jet are nonsimilar in incompressible flow. This precludes obtaining closed solutions to the pertinent boundary equations, and numerical solution techniques will have to be used.

The second part is the impingement region. This region is the most difficult to treat theoretically. With our present knowledge of fluid mechanics, the best that can be done is to make some reasonable assumptions as to the velocity and temperature fields in this region based on an understanding of the gross characteristics of the jet. The boundary conditions must obviously include a smooth transition from the free-jet region and to the third part of the jet, the so-called "wall-jet" region. In this region the flow field gradually expands as the fluid flows along the surface away from the stagnation point. Incompressible wall jets have been treated extensively in the recent literature from the momentum transfer standpoint. The heat transfer and compressible flow case remain to be investigated. Both similarity and integral methods are presently being considered for handling the analysis of this region.

Experimental equipment designed to test analytical solutions and some of the initial assumptions is nearly complete.

A need for a "simulation laboratory" at Washington University had been evident for some time, but none of the several research projects requiring it were in a position to fund completely the establishment of the laboratory. With the aid of the multidisciplinary grant, it became possible.

The laboratory consists of two principal research tools, an analog computer and a small general-purpose digital computer. Each can be used separately. But, when connected, they become a system by which one can study the digital control of processes simulated by analog equipment. Although the immediate interests center on physical processes, the same procedures can be used to study biophysical and biological systems and their control mechanisms.

One other project, a NASA supported project and a very active one, in the Economics Department of Washington University, is entitled, "Analysis of the Impact of Space Activities on the National Economy and Establishment of a Methodology for Determining Space Program Effects on Regional Economic Growth." This project was begun a little over 1 year ago.

The Economics Department is undergoing a period of rapid development at Washington University. The number of graduate students has doubled in 1 year from about 37 to 70; it is a very active group and a very exciting development to watch. Among its researches, under the NASA grant, are some of the following topics:

(1) Regional expenditure impact studies
(2) Economics of scientific research and manpower
(3) Research on distribution of technological information
(4) Legal and economic studies of new towns (there is a collaborative effort on this phase in the School of Law)
(5) Legal problems of land assembly
(6) Effects of research and development and government contracts on community and regional development
(7) An economic analysis of communications satellite systems
(8) Initiation of the establishment of an economic and sociological Data bank of computer tapes
(9) A conceptual analysis of the economic significance of NASA-type outlays, huge outlays, that may occur when a special new program such as the space program may be initiated by the government.

This is another example of a project that helps to illustrate the broad swath that has been cut across the campus by NASA's support in actually a little more than 1 year. Only one of the projects mentioned, astrophysical investigation of the primary cosmic radiation is of duration substantially exceeding 1 year.

In summary, the Multidisciplinary Research Grant effectively supplements project support of programs relevant to space science. First, it allows new faculty members quickly to establish their research activities with a delightful freedom from loss of time or research momentum. The avoidance of a psychologically depressing research hiatus is beneficial to the faculty member, to his students, and the Nation's science effort. Second, it permits established faculty members to initiate research efforts in a promising new direction with a minimum of inertia. A quick uptake is possible with this grant. Third, it can supplement several related smaller projects in providing a much needed research facility or service that the projects individually or even collectively cannot afford. These advantages are especially important to an institution, such as Washington University, with a rapidly expanding and developing program in the sciences and engineering at the graduate and research level. (In the next 5 years, the number of graduate students should double in engineering and physical sciences at Washington University.)

It is interesting to note that of the faculty members whose research has been supported by NASA's Multidisciplinary Grant during its first year, 44 percent were in their first year on the faculty when they were awarded the NASA Multidisciplinary support, and 19 percent were in their second year on the faculty. Of the six faculty members who were of greater faculty seniority with Washington University, two were enabled to set off quickly in new research directions, two were able to obtain a research facility beyond the means of their individual projects, and the remaining two were people of some seniority working with some of the younger faculty members mentioned earlier.

This incomplete set of statistics, from a rather small grant by comparison, is indicative of the extremely effective way in which multidisciplinary support can be woven into the structure of a developing university.

Session IV—Space Flight Experiments

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Policies for Scientific Participation in the NASA Space Flight Program

John F. Clark

DIRECTOR OF SCIENCES

OFFICE OF SPACE SCIENCE AND APPLICATIONS, NASA

As an introduction to this session I would like to review briefly the policies we have developed for the formulation and conduct of the space flight program of the Office of Space Science and Applications.

The NASA space science flight program is first and foremost a research program in many fields of basic and environmental sciences. Its objectives are suggested by space scientists themselves. Each individual flight project has its own particular scientific objectives which are the direct result of suggestions by our fellow scientists. Thus, we may make more accurate observations of solar phenomena or investigate the configuration of the boundary of the Earth's magnetic field. In any event, we develop the project so as to increase scientific knowledge of the environment of and phenomena in space. We do not undertake a project merely to secure technological data.

Both the need for and the broad specifications for a new space flight project are established by the NASA scientific discipline advisory subcommittees. The Advanced Orbiting Solar Observatory is a good example. Early in 1960 it was recognized by solar physicists that a need existed for an observatory with better pointing accuracy and more space for instruments than is provided by the existing Orbiting Solar Observatory. A meeting of the Solar Physics Subcommittee was held to examine the need for the satellite and to determine its required pointing accuracy and size.

After having established the requirements for such a mission and receiving the necessary executive and congressional support, we proceed to define the mission in great detail. We arrange for the development of the spacecraft; we assure the availability of an appropriate launch vehicle; and we establish project organization to provide management. We notify the scientific community that we plan to fly the spacecraft, describe its capabilities, and invite scientists to propose investigations for flight on the space vehicle. Parenthetically I should state that an invitation to propose experiments is accompanied by an invitation to scientists to suggest other projects that should be included in the future space science program.

This notification to the scientific community is done primarily by sending to hundreds of individual scientists copies of a document entitled "Opportunities for Participation in Space Flight Investigations" (ref. 1). We send copies of this document to all U.S. laboratories that have demonstrated competence or indicated interest in space science, and to the space organizations of foreign countries for transmittal to their scientists. Any interested scientist may propose to carry out an investigation. The proposals are received by NASA and are reviewed by one or more of the appropriate scientific discipline advisory subcommittees. There are seven of these, in the disciplines of astronomy, bioscience, ionospheres and radio physics, particles and fields, planetary atmospheres, plantology, and solar physics. The majority of the members are outstanding university scientists, with the balance of the membership drawn from their equally outstanding scientific colleagues in Government laboratories. The committees are chaired by scientists who are NASA Headquarters employees and are not eligible to participate as investigators in the space flight program. The criteria which the subcommittees use to evaluate a proposal are:

- The scientific merit of the proposal, including whether it needs to be done on a spacecraft or can be done on the ground or in a less expensive vehicle such as a balloon or sounding rocket
- The ability of the proposed experimental apparatus to accomplish the objectives of the experiment
- The competence and background of the scientist who proposed the experiment
- The interest and ability of his institution to provide the necessary administrative and technological support.

The proposals are placed in four categories by the subcommittees. The investigations placed in Category I are recommended for flight on the particular mission. A Category II experiment is considered to be suitable for flight but at a lower priority than Category I. Category III experiments are judged to be equal to Category I in terms of scientific desirability, but in need of further development before they are ready for flight. Assignment to this category carries with it a recommendation that NASA provide support to develop the experiment for future flight. Category IV experiments are those which are considered to be unsuitable for the particular flight under consideration. Subcommittees do not evaluate laboratory or rocket experiments nor do they "plan" experiments.

Experiments placed in the first two categories are sent to the NASA field center that has the project management responsibility for review of the technological compatibility of each experiment with the spacecraft. A payload is then recommended by the director of the Headquarters Program Office in OSSA that has responsibility for the flight mission. This payload is presented to the Space Science Steering Committee which is made up of senior scientists and engineers in OSSA. The Steering Committee reviews the Subcommittee recommendations, the technological evaluations by the NASA center, and the recommendations of the responsible program director. The Steering Committee makes a recommendation to Dr. Newell, Associate Administrator for the Office of Space Science and Applications, who makes the final determination of the payload for the mission.

The sequence from the investigator's standpoint might be: A principal investigator first receives the "Opportunities" document. He then prepares his proposal which he sends to the Office of Grants and Research Contracts. If he is selected, a contract is negotiated with him by the NASA center that has project management responsibility. Under this contract, he designs, manufactures, tests, and calibrates his equipment. He may do this himself or subcontract the work to industry. He then brings his equipment to a testing laboratory which may be at a NASA center or at the plant of the industrial contractor who has the responsibility to NASA for building the spacecraft. There, the experiment is subjected to a variety of tests to ascertain if it will sustain shock, temperature, and pressure variations, and if it is magnetically "clean." After having passed such tests his experimental equipment is integrated into the spacecraft, which in turn is put through a series of final environmental tests and launched.

If the mission and experiment both are successful he receives his data and proceeds to analyze and interpret them. This leads to the end product—the publication of the results of his investigation. Out of it, he and other scientists formulate new questions, and new cycles begin over again. After a predetermined period of time, ordinarily 3 months to 1 year, the reduced data from the investigation are made available to all scientists to use if they so desire.

What kinds of support are available to groups who are interested in space research? There are supporting research funds which are available from NASA headquarters to develop an idea or instrument, or to provide supporting theoretical, laboratory, or ground-based observational research for the program. We frequently provide flights on sounding rockets to new investigators to enable them to get experience with instruments in actual space flight. Sounding rockets also are used to test their experiments before they are flown on satellites or space probes. There are the large Orbiting Geophysical Observatories for those who want to make measurements correlated with those in other disciplines or who want to construct a minimum of hardware themselves. There are Explorers for which a group of scientists in an organization such as a university or a Government laboratory can propose to develop a complete payload. Such a group must accept full responsibility for the design, manufacture, and testing of the experiments and the complete spacecraft, including its structure and power, telemetry and command systems. Finally, there is an opportunity to use the data from past space flight experiments for additional study as a basis for the correlation of large-scale geophysical phenomena, as support for or test of a theory, or as a starting point for a new experiment.

What are the current chances of selection for a scientist who proposes an experiment? We were able to fly about one-third of the experiments which were proposed for OGO C and D. We expect to be able to fly about two-thirds of those proposed for OGO E. In the smaller Explorers, we have been able to fly about one-half of the experiments proposed. These figures include all proposed experiments, whether judged suitable or not by the subcommittees. Our experience has shown that, although the competition is keen, every competent group that has made a serious commitment to space research has been able to qualify for a substantial fraction of the space flight opportunities which it has requested.

How long does it take to conduct an experiment in space? It takes much longer than we would like. For a new ground-based laboratory experiment, I would judge that from 3 months to as much as a year is required for an experimenter to receive a go-ahead and at least another year to complete his research, depending upon its complexity. The time required for publication of results should be added. Experiments destined for space flight require longer times for many reasons, including the greater complexity, ruggedness, and reliability required for such instruments. Here, the required time may stretch to periods comparable to those required for development of a new astronomical telescope. With an Orbiting Geophysical Observatory, 33 months pass after NASA receives a proposal while the experiment is selected, contracted, developed, integrated into the spacecraft, tested, and finally flown. Subsequent reduction of data and publication takes another year or more after the spacecraft ceases to transmit data.

We are looking hard at many ways of shortening the leadtime for an experiment. We hope that with increasing experience we may be able to shorten the integration and test periods. However, an investigator who now proposes a new experiment should plan on a period of 3 years or more from the time that he submits a proposal to the time that the experiment flies on a satellite or space probe.

REFERENCE

1. Opportunities for Participation in Space Flight Investigations. Office of Space Science and Applications, NASA, July 1965.

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Space Flight Experiments in a Graduate Physics Program

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SPACE PHYSICS AS A PART OF PHYSICS

THE TOPIC "SPACE FLIGHT EXPERIMENTS IN A GRADUATE PHYSICS PROGRAM," I think, states the central problem in the university. Although the support to universities given by NASA is of many types, including graduate student fellowships, undergraduate support of various kinds, facilities, and various kinds of grants and contracts to support experiments, I believe that in the longrun this effort will not be successful unless a group of challenging and exciting problems become available on which graduate students can carry out their Ph. D. thesis research. This kind of research is the core of the graduate program of the Physics Department of the University of Minnesota and, I am sure, elsewhere. One of the most vexing problems is the implementation of space probes, satellites, and rockets for this type of research. At times even after some experience in this field, one wonders whether, in fact, this is at all possible. However, with our own program, in a modest way we have been able to use space flight experiments for Ph. D. thesis problems. A number of observations, difficulties, and results with this program are discussed herein.

In my own approach to this problem there are several basic assumptions. One of these assumptions is that we are training professional physicists; that is, the space physics program as a specialty shall be on the same basis with the other areas of modern physics, such as solid state physics, nuclear physics, low-temperature research, and high-energy physics. This type of research must be suitable for carrying out in a modern physics department. The investigations must be such that they will lead eventually to the solution of specific problems which will advance physical knowledge. The difficulties begin with the name, "Space Physics," itself. This title is actually not readily accepted by physicists in many areas who regard space as an aspect of physics connected with relativity and cosmology, which has been a subject of physics for many years. The category of experiments which nowadays is known as space physics research arises because the experiments occur in the environment of outer space, in the popular phraseology, and sometimes we get some snide remarks from our fellow physicists about this.

Another assumption, which follows on the first one, is that the basic training that students in the area of space physics receive shall be the same as that for other areas of physics; that is, the specialization shall occur in the same manner that we have been accustomed to having it in all branches of physics in the later years of graduate study. My own personal choice is not to undertake a new problem unless a competent graduate student is available to work on it and will eventually assume full responsibility for the conduct of the investigation. This leads to a direct collaboration between the student and the professor in the research work. Both are educated by the process. Since most physics staff members have at least one regular physics course to teach, this implies that if a number of graduate students are working on problems of Ph. D. caliber, the amount of administration and number of similar types of activities that can be carried out by the professor must be rather limited. It seems to me that if NASA is anxious to make the research professor effective in his major job, which consists of research and student training, it should seek to unburden the principal investigator of details such as unnecessary red tape, phone calls, and requests for information.

In preparation for graduate work in the area of space physics there is no substitute for a strong and diverse background in undergraduate physics. This should include mechanics, electricity, magnetism, atomic and nuclear physics, statistical mechanics, optics, introductory quantum mechanics, and, if possible, a course in astronomy at the undergraduate level. Many undergraduates, because of the popular interest in space research, have an early interest in this subject. I advise such students to pursue their general physics program and to do well in it. However, there are some possibilities for special training if the student is interested. At Minnesota there are many undergraduate assistants; also, there are many physics majors who work part-time during the academic year and full-time during holidays and summers assisting graduate students and helping in general with the many features of upper atmosphere and space experiments. Some of these students continue into graduate school in the same field. This kind of undergraduate preparation is very valuable, and the able student can profit by it. However, this kind of training is not necessarily better than good advanced laboratory courses in atomic and nuclear physics, optics, or electricity.

GRADUATE PHYSICS PROGRAM AT MINNESOTA

All first-year students in the graduate program of the Physics Department of the University of Minnesota are required to take a graduate course in atomistics and elementary quantum mechanics, which is followed in the first quarter of the second year by a course in advanced quantum mechanics. They must also take a sequence in theoretical physics and relativity and various mathematical courses of suitable nature. Minnesota operates on the quarter system, and between the winter and spring quarters a general comprehensive written examination is given to all first-year graduate students. Success in this examination qualifies the student for consideration for the Ph. D. program. The student is strongly urged to complete one of his language requirements during the first year, preferably by the end of the fall quarter of the first year. The student is also instructed to utilize the fall and winter quarters to become acquainted with the complete program of research of the department by attending seminars and colloquia, by talking with the research groups in the laboratories, and so forth. Upon successful completion of the Ph. D. qualifying, a student is then required to select an area of interest, and, by mutual agreement, select a research advisor. The factors that influence which field of physics a graduate student chooses are many and varied, but he looks into such things as whether he can finish his Ph. D. thesis in a finite length of time, whether the problems are exciting, and whether the field is an active one, so that he can secure a job in a university, government, or industrial laboratory after he finishes. For this purpose he talks with other students and gets a very good picture of the field, including the specific opportunities for young Ph. D.'s to obtain research or staff positions in other universities. If the field of research is not adapted for furnishing good Ph. D. problems, then this laissez-faire method will not provide competent students in the area, and this means that the health of this area of research will suffer. The second and third years are generally occupied with more specialized courses in the area of interest and with fulfillment of the quarter credit requirements in the major and minor areas according to the agreed upon three-year program. In the area of space physics at Minnesota, this would include a seminar in cosmic rays and atmospheric physics and such courses as astrophysics, plasma physics, cosmic ray physics, hydrodynamics, differential equations, function theory and analysis, Fourier analysis, computer programming and technology, and vector and matrix theory.

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The second language requirement must be fulfilled in this period. Following the appointment of the Ph. D. examining committee the oral prelim is taken. This may occur at the end of the second year, but it is more likely to occur sometime in the third year, and sometimes occurs in the fourth year. Presumably, the fourth year will be mainly occupied with thesis research which, in my own field, will be in experimental physics and, therefore, be hopefully at the data acquisition and analysis stage. The completion of the thesis and the final Ph. D. oral, more often than not, goes over into the beginning of the fifth year, but by this time the student is generally in the category of a research associate and may finish the year enlarging on his research problem or otherwise continuing actively in the experimental program.

What I have discussed is, of course, more or less similar to the pattern in any modern field of physics. I have put in details, because it is within this framework that the choice of the thesis problem must be made. In the Minnesota graduate school a master's degree is not simply regarded as a consolation prize for those who do not successfully pass the Ph. D. prelim, but rather the master's degree can be taken as part of the Ph. D. program. The course requirements can be completed in 1 year, and these courses will also serve on the Ph. D. program.

CHOICE OF SUITABLE PH. D. PROBLEM

The most important moment of decision, in my mind, at least, is in the first year when the student and advisor decide on a suitable Ph. D. problem, if it is in the first year. It is absolutely imperative to begin the investigation early in the graduate career if there is any hope at all of completing an experimental program on a rocket, satellite, or space probe. Some of the types of problems which are of interest at Minnesota include an investigation of the energy spectrum and the composition of primary cosmic rays in the Galaxy and the study of high-energy particles accelerated in solar flares and their propagation to the earth as well as their interaction with the magnetic field of the earth. Of particular interest in the cosmic ray field is the study of the 11-year cycle of cosmic ray intensity following the solar cycle itself. The causes and modulation mechanisms are of current great interest. There is an area of investigation in the studies of the upper atmosphere composition, including the ozone and the infiltration and diffusion of dust and its origin, and this has been extended to a study of the zodiacal light and airglow and the outer corona of the sun during eclipses. There is theoretical and experimental interest in the structure of the magnetosphere around the earth, particularly the interaction between the magnetic field and the solar windstream of ionized plasma, the mechanisms by which hydromagnetic shocks may be formed, and the production of energetic particles in the electric field near such shocks. We also have a long-term interest in the fundamental aspects of the Van Allen radiation regions, particularly the origin of the energetic electrons that are found there. Over the past 17 years there has been a large effort in problems of this type using high-altitude balloons, but following 1959 there has been a growing program in which experiments have been successfully carried out on rockets, satellites, and space probes to investigate these problems.

The all-important decision comes in the first year when, if possible, a problem is selected jointly by the professor and the student. I have developed the philosophy, as a result of considering these situations, of not proposing a specific space experiment unless a competent graduate student is available to carry it out. On the other hand, a graduate student will probably not choose to work with a staff member unless that staff member has a number of interesting problems on which he can begin.

At this point I would like to take a concrete example. In the spring and summer of 1961, it became apparent that the main intensity of the trapped electrons in the large outer regions of the radiation belts was produced within the confines of the magnetosphere and was not, for example, injected from the solar stream. It became clear that good spectra of the energy and distribution of the pitch angle of these electrons would lead to choices between various mechanisms proposed for their origin. Because of the ambiguous interpretation of simple detectors flown on earlier satellites, we decided to build a good magnetic spectrum analyzer for the trapped electrons covering the range from 50 kilovolts to four million electron volts. A promising graduate student who had actually been an undergraduate at Minnesota and had done exceptionally well as a physics major agreed to undertake this task.

When a student discusses a specific space experiment with me, I make it clear that a rocket may not end up in orbit but in the ocean or some other place and if he is going to do this type of experiment, he has to have full knowledge of the risks involved.

This physics student set about to design a magnet to test detectors on a prototype model. A proposal was made to NASA to include the spectrometer on the first of the new OGO series of geophysical observatories, and the proposal was eventually approved. One of the early tasks involved frequent conferences with the electronics shop to work out the logic for the system so that suitable dynamic range and suitable data storage could be fitted into the data system of the OGO satellite. The graduate student was given a great deal of support in the electronic design details; several competent design engineers worked on the circuitry, particularly the megacycle response amplifiers, and the various discriminators and logic circuits were developed. Parallel with this, the graduate student designed a magnet by plotting trajectories, had a preliminary model built in the shop, and assembled this with the detector. The final model for the prototype was built, and eventually the complete prototype experiment was assembled. This prototype was then arranged to fly in a rocket payload to be launched from the Pacific Missile Range into the inner-radiation zone. Since we had no real knowledge of the effectiveness of the shielding and the background corrections to the electron spectra, this rocket experiment proved to be extremely valuable, because the spectrometer showed some serious defects. The shielding was insufficient to protect the detector from the background flux of radiation, and the counting rates coming through the analyzing magnet were indistinguishable from the background flux, that is, in this rocket shot. Although this was largely due to the intensity of the "starfish" nuclear radiation still remaining in the inner zone, a substantial redesigning was done of the detector system in preparation for the prototype for the first OGO payload. The prototype was followed by a flight model and flight spare. The flight model was integrated into the payload which was successfully launched on September 4, 1964. Although the performance of the first OGO was not in all respects successful, nevertheless, this experiment is accumulating a large amount of excellent data, and this student has every prospect of a first-rate thesis.

The first consideration of this experiment I found was in one of my notebooks dated March 14, 1961. In the summer of 1961 we began work on the spectrometer magnet. In December of 1961 the student, in the middle of his first year, undertook the program. The OGO proposal was made sometime in this period and was approved. The summer of 1962 was occupied with very intensive work to build the first experiment. In January of 1963 a complete engineering model was finished and was flown on the rocket in February of 1963. In April of 1963 a prototype unit was delivered to the NASA Goddard Space Flight Center for acceptance tests. In September of 1963 the first flight unit was tested at Goddard, and in March of 1964 the second flight unit was tested. The launching of the satellite occurred in September of 1964, and in December of 1964 the student presented a 10-minute contributed paper giving the first results of the experiment at a meeting in Seattle of the American Geophysical Union.

Thus, the time from the concept of the experiment to the first presentation of data was 4 years. The student is now in his fourth year in graduate school, and he has occupied the entire 4 years of his graduate career on this one experiment. If the shot had been a complete failure, he would have had to wait another year for a repeat. To guard against this, another rocket experiment with a somewhat different version of the spectrometer was prepared, and this rocket experiment is now about ready to be flown. Fortunately, the first OGO was successful so the rocket experiment will serve to add to the information in a special way at lower altitudes. The student rapidly became master of the experiment. He became familiar with the entire OGO program; he attended the experimenters' meetings and traveled to the payload laboratories to participate in the integration and to the Goddard Space Flight Center where the package was environmentally tested. He also worked out the computer programs with Goddard and with the computing center at Minnesota so that the quick-look data and flight data could be analyzed. Although he did not actually do too much of the design work in electronics, he worked closely with the people who were doing this, checked out the final version, and put the unit through the environmental test to make certain it was reliable. This included numerous high and low temperature tests, vibration tests, calibrations, compensations for gain changes with temperature, complete evaluation of the exact characteristics of the electronic energy analyzer, and the uncovering of a considerable series of difficulties such as faulty components and mistakes in wiring.

Of course, during all this time he was working on his formal graduate program. In the fall quarter of the first year, he took mathematics courses, theoretical physics and quantum mechanics. In the winter quarter, he took atomistics, properties of solids. In the spring, he took the same three courses again. In the fall quarter of the second year, he took mathematics, advanced quantum mechanics, and theory of complex variables; in the winter, mathematics and complex variables; in the spring, principals of mathematical physics and theory of complex variables. In the fall and winter quarters of the third year, he took plasma physics and cosmic ray physics. In the spring he added another course in mathematics and finished the cosmic ray and plasma physics courses. This year he is taking courses in astrophysics and computer programing, and he is participating in the advanced seminars.

SUPPORT

It is my belief that if a student is going to work in this area of research he must become a master of every phase of it. He must know as much about the electronics as the electronics engineers who design the equipment. He must know as much about mechanical features as the mechanical design engineer and the shop personnel who build his magnets and parts. He must have a complete background in the physics of the radiation regions in which he is going to make measurements, and he must know what the measurements are going to be and how the data can be used to advance the state and the art. He must have confidence that the instrument will be able to get unambiguous data when it is put into orbit. He must also know very well the characteristics of the spacecraft, how the data system works, and in what form the data will be returned. He must also know the procedures to be used for analyzing the data. Although it is my philosophy that the graduate student must be a master of his own experiments in every respect, it is nevertheless necessary to give him substantial support of many types. We have generally found it advisable that he be given a full-time electronic engineer to assist him in designing, inspecting, and building of the final stages of the experiment. This engineer must be completely familiar with the experiment and must be able to travel to the payload laboratories for integration tests whenever necessary. This is necessary because the graduate student's schedule of courses and examinations does not always allow him to travel. He must be provided with a competent complete electronic facility to design and build the printed circuits and other parts for such specialized equipment. He must also have a competent machine shop facility available. He must have a computer facility available and, preferably, assistance with programing, which, in our case, is often provided by another beginning graduate student or a proficient undergraduate student. He must have assistance with computation, filing of data, care of tapes, and so forth. All my students who build such equipment follow it to Cape Kennedy for the final checkout and watch it being launched into orbit. If the shot is successful and the data are good, then a new problem presents itself. This new problem, which is one that can be faced with great pleasure, is to decide to which scientific meetings the data should be presented and in what journals the data should be published.

In regard to the overall conduct of the support of research, one item which I believe is proper to completely spare the student is the arrangements leading to such matters as the research support and the hardware contracts and proposals. He will get a full dose of this when he first gets on his own in some new university position. Since the first space flight experiments at Minnesota, we have witnessed a continual transition of the method of support of this effort. The first method of support was a research grant which involved construction of the flight equipment. This grant, however, was replaced by two kinds of support. One is long-range support, and the other is hardware contracts. NASA only enters into negotiations for the latter when an experiment has been approved for inclusion in a payload.

However, the long-range support grant is provided so that new ideas may be developed and so that funds will be available for work on a new project before the hardware contract is negotiated and for many other general support purposes.

This research support grant has also been used to support visiting research associates and to help the program in which visiting NASA fellows from abroad come to the laboratory to study.

The graduate student discussed previously was appointed by the university as a NASA fellow under the NASA traineeship program at the beginning of his second year.

EXPERIENCES OF A SPACE PHYSICS GROUP

There are about 9 or 10 faculty persons in the Department of Physics working in the area of upper atmosphere or cosmic ray physics, or if you like, space physics. There are between 20 and 25 active graduate students. Currently, five of these are attempting Ph. D. theses on a satellite or space probe. Of the five, two on the OGO mission are receiving data in their fourth year of graduate school. One of the others is now beginning a new program in his second year with the launch date for the satellite set in his fourth year, in late 1966. Another one is in his third year with the launch set for his fourth year. One is in his second year with the launch set for the end of his fourth year or his fifth year. Of these last two students, one came into the program late and did not really participate to the desired extent in the design of the experiment, although, as a result, he got aboard closer to the actual launch date. But, the difficulty was that his participation in the thought behind the design of the experiment was not as much as the professor concerned with it would like it in any respect. The last student, who has been active in the design concept of the experiment, will wait 5 years for his data. Neither of these last two are satisfactory.

The timing, if a student is to take full advantage of participation in a satellite or space probe, becomes extremely important

The other 20 students are working on rockets, balloons, or ground-based measurements.

The staff members do not agree on how the time of the students should be spent. One of them, at least, has strong feelings that students should not work on satellite and space probes. This member believes that this type of program is not suitable because of the long leadtime and the difficulty in doing follow-up experiments to test the student's ideas. It is true that a follow-up experiment in this field frequently involves the next generation of graduate students.

The staff members are generally agreed that a Ph. D. problem using data analysis alone is undesirable. If it is an experimental program, we consider it essential that the student actually participate in the design and building of the experimental apparatus; otherwise, he will never know what it means to make a physical measurement. This is not necessarily true of theoretical students. They use data, of course, very liberally, but they have other problems. One can see that the number of experiments that can be made in a logical manner toward the solution of a problem is sharply limitetd in one's lifetime. So it is clear that one of the problems is to find ways to decrease this leadtime.

At Minnesota, a new group is beginning. The professor in charge has some new and exciting thoughts about the structure of the standing shock wave, which is believed to exist around the magnetosphere. This is an extremely interesting situation, which has come to light in the past 2 years. The earth with its dipole magnetic field is situated in a supersonic wind which is blowing out from the sun; by analogy with any object in a supersonic stream, a standing shock wave does seem to exist, but the mechanism by which a shock can be formed in this collisionless plasma is not understood. A new research associate will begin a program of experimental investigations aimed at measuring the shock, and he will be assisted by several promising students. In order to study the structure of this magnetospheric shock, measuring devices must be sent out between 20 and 30 earth radii. There is only one way to do this, namely to put the device on board a satellite with a highly elliptical orbit.

The most logical thing to do at this point is to examine reference 1. A suitable vehicle can be provided, but a minimum leadtime of 3 years will be required. In the meantime, of course, there is always the danger that a mission already in orbit may essentially solve most of this problem, and the new group's efforts will have to be diverted or otherwise used.

I like having my own students do the most exciting experiments, because I think it is very critical to get new ideas and new approaches. These exciting experiments, in our field, frequently turn out to be on space missions.

REFERENCE

1. ANON.: Opportunities for Participation in Space Flight Investigations. Office of Space Science and Applicaions, NASA, Jan. 1965.

COMMENTS

Madey, *Clarkson College of Technology:* Did the student who conducted the space flight experiment get a master's degree along the way, or did he select and integrate the master's thesis with the Ph. D. thesis?

Winckler: He did not get a master's degree. The question of whether or not to obtain a master's degree is difficult to answer. I think that if the student is extremely competent, then he can work towards his Ph. D. degree without first getting a master's degree. If he doesn't know whether he likes the field, he can concentrate on a master's degree. If he is not sure that he can succeed in an experimental subject of Ph. D. quality, then it may be that he will choose to unite a master's thesis first, which can be quite restricted and can be done as a part of the Ph. D. problem later (if it does not get out of hand). The master's course requirements may also be used towards the requirements for the Ph. D. degree.

Hancock, Purdue University: When a student assumes the responsibility of a research program, are the ideas for the program primarily generated by the professorial staff or are they the ideas of the student? One of the problems in engineering at Purdue is getting the student ready to assume the responsibility of a research program; he must have the necessary course background. He has usually passed his master's program and is beginning his doctor's program. Therefore, is this student doing anything any more than a bachelor student could do?

Winckler: The student grows into the problem as he always does in doing a Ph. D. thesis. He does not know everything at the beginning. He is studying physics in graduate school. He is confronted with a completely new situation and he must first have the initiative to try a space flight experiment before undertaking it. I think this is the essence of training that distinguishes a good student in this field from one who should not be doing this sort of thing. I think that many graduate students can carry out space flight experiments if they are given a chance.

Eshleman, Stanford University: I also think that some of these problems are compounded very markedly when we talk about deep space probes as opposed to satellites, rockets, and balloons. I think you'd be doing a disservice to people who are contemplating beginning in some of these areas if you had not indicated what some of the problems are. I would like to know whether others have had the traumatic experience we have had in getting started in an interface with NASA headquarters, the NASA centers, industry, our own business organizations, and so forth, in terms of the various aspects of getting involved in a deep space experiment.

Winckler: I am glad you brought this up, because I think the deep space flight experiments are much more difficult that the earth satellite experiments. Planetary opportunities are further apart than the normal launch intervals of earth satellites. Also, one has to wait for such a long time to get data. There are not only the uncertainties of whether the spacecraft is going to work immediately after launch, but in the case of Mars, the uncertainties of whether it is going to work for about 9 months after launch. Therefore, because the deep space flight experiments are so much more limited numerically, so much more expensive to carry out, and so much more uncertain, I would never suggest to a graduate student that he involve himself with this type of experiment for a thesis topic.

Eshleman: I think that Dr. Winckler has made it much more attractive; I think that the use of earth satellites would be much more realistic.

Winckler: The question as to whether or not there is a steady state condition is one of the points that I discussed with our various staff members in Minnesota in this area. They are against having a Ph. D. student do a data analysis program. If he is a theoretical student, he should be doing a theoretical calculation and using data. In the Physics Department we have found that we have to do our own electronics and our own mechanical design. The electrical engineers are not interested in electronic design just as a service function to the Physics Department, and I think I understand why. They are trying to get interested in basic factors of electronics and electrical engineering, and they are not interested in participating as circuit designers for the Physics Department.

Smith, University of Florida: You mentioned periods of the order of 4 or 5 years in connection with your graduate students in this program. Is this more or less typical of the time taken by all students in the department, or do graduate students in your program take longer on the average than those working in ground-based aspects of physics, for example?

Winckler: So far the students in our area who have participated in space flight experiments for their theses have not taken longer than other students. I have looked into this problem from the standpoint of the head of our electronics shop, the head of our machine shop, and other people who are looking at the students going about their tasks. What do they think about it? They do not see very much difference between our students and those who are working in solid state physics, nuclear physics, or some other area. Perhaps they are not seeing the whole story, but the progress of this student in graduate school is essentially not too different from that of other students except that he has to do one thing more. He has to make an apparatus which is so reliable that it will continue to work for a year after it is launched under conditions that are out of his reach; this is somewhat different than the situation for the student who is doing a laboratory experiment and can resolder a wire or turn a knob.

Dayton, Montana State University: For some time I have had the feeling that certain areas of high-energy physics are certainly inappropriate for a Ph. D. thesis and that training in these fields of high energy physics probably should be pursued strictly as a postdoctoral operation. I get the impression that although you may not believe that this situation also holds for the satellite flights, there are people who would agree that satellite experiments should be restricted to the postdoctoral area. Is this correct?

Winckler: That is right. One of my closest collaborators at Minnesota feels strongly this way. He does not want his students working on satellite programs. One of the difficulties is that the leadtime is very long, the assurance of success is to some extent questionable, and a student could get involved in a still longer time. But more important is the fact that the student cannot develop his approach to the problem by trying things and then correcting the experiment. This problem of the followup is almost impossible with satellite experiments. So one must design an experiment which is known ahead of time will be able to give an answer that will make a contribution and one must do this at least 3 years ahead of the time that the measurement is made.

Madey: The electronic engineer that you assigned to the graduate student on a full-time basis is an important part of the machinery to get an experiment going. You have a going program. Can you give advice on how a new organization might start a space flight experiment where such an electronic engineer is required?

Winckler: I think an appropriate person is a student who has a B.S. degree in physics or electrical engineering and who wants to start working. If you are in a university you may have these people around. If you do not have them at your own place, I think you can find lots of them around that will find this exciting and will want to do it for a period of years as a stepping stone to a future permanent job in industry, for example. This is a very good stepping stone for them, and if they can be given the right kind of appointment, it can be made attractive and they will do a good job.

Experiments in X-Ray and Gamma-Ray Astronomy[1]

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DESCRIBED HEREIN IS A NASA-SUPPORTED EXPERIMENTAL PROGRAM which has as its objective the search for cosmic photons in the general range of about 10 keV to 5 MeV. This program uses both balloons and satellites as vehicles; experiments on balloons provide background information, detector studies, and, hopefully, observations of certain specific objects. The major observations are provided by satellite-borne instruments.

Interest in these observations had its origin during my graduate years at the University of Minnesota, under the direction of Dr. John R. Winckler. During the International Geophysical Year we observed several cases of X-ray bursts from the sun during solar flares. Studies of these events provided considerable new information on solar flares and caused one to speculate on other possible sources of a stellar or galactic nature. About the same time evidence from optical and radio astronomy caused astrophysicists to predict detectable fluxes of X-rays and gamma rays at the earth from various celestial objects. This program was started at the University of Minnesota about 1960 and is continuing at the University of California at San Diego (UCSD), where I have been located since 1962.

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[1] This research was supported under NASA contract NASw–56 at the University of Minnesota and grant NsG–318 at the University of California at San Diego, as well as under contracts NAS5–3122 and NAS5–3177 with the NASA Goddard Space Flight Center.

OSO–I EXPERIMENT

After a few preliminary balloon measurements of the gross features of the cosmic-ray-produced, gamma-ray background in the atmosphere, an exploratory experiment was proposed for the first Orbiting Solar Observatory (OSO). This experiment was designed to provide broad energy and angular resolution for nonsolar gamma rays, to monitor the sun for solar bursts, and to provide information on the general background. The experiment covered the region of the spectrum from 50 keV to about 3 MeV.

A functional diagram of the instrument is shown in figure 1. A simple NaI scintillation counter with a lead pipe collimator provides

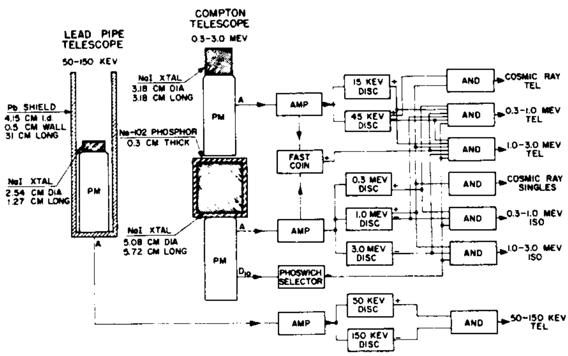

Figure 1.—Block diagram of an exploratory experiment in gamma-ray astronomy designed for the First Orbiting Solar Observatory showing gamma-ray detectors and detector logic.

a directional detector in the range of 50 to 150 keV. At higher energies, lead collimators are known to produce more gamma-ray background from cosmic rays than they attenuate, so a device known as a Compton telescope was used. This device uses two scintillation counters in coincidence. By placing a requirement on the energy of an electron scattered by an incoming photon, one obtains a device which has a directional response to gamma rays. As designed for the OSO–I satellite, the Compton telescope had an angular response of about 24° full width at half maximum for Co^{60} gamma rays, a rejection factor of about 30 at large angles, and a forward efficiency less than 1 percent. The total isotropic gamma-ray flux was measured with the absorbing counter of the Compton telescope, which was a 2- by 2¼-inch NaI counter of the phoswich type. This type of counter rejects edge effects due to charged cosmic rays and other particles. In addition, overall isotropic and coincidence rates were monitored to provide a measure of cosmic-ray effects. These rates were monitored when the satellite was in a night mode, and direction references, required for operating the telescopes, were not available.

The instrument shown in figure 2 was designed to fit in the wheel compartment of an OSO satellite. The instrument weighed about

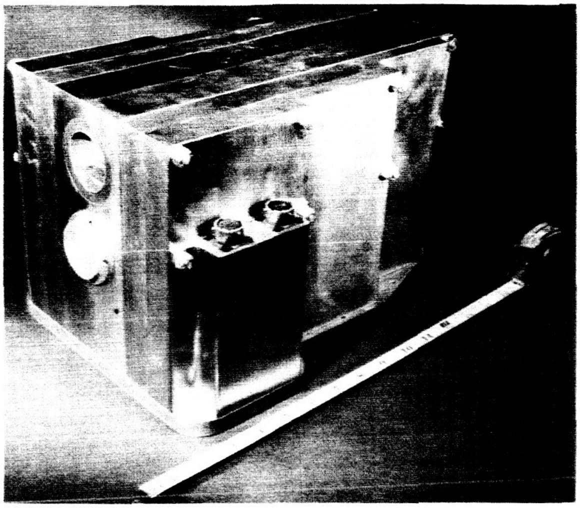

Figure 2.—Photograph of the OSO–I instrument. The instrument weighed about 30 pounds, contained 400 transistors, and drew 0.5 watt of power.

30 pounds, had about 400 transistors in it, and required about 0.5 watt of power. The entire instrument was designed, constructed, and tested in the laboratories and shops of the University of Minnesota.

Since not everyone is familiar with the OSO series of NASA satellites, a brief description is in order. A photograph of the first OSO is shown in figure 3. An OSO has a wheel section, which rotates at about 0.5 rps and provides a stiff axis for torquing against. The wheel axis is servocontrolled to lie a plane perpendicular to the earth-sun line. A directional experiment, placed in a compartment of an OSO and facing radially outward, sweeps the sun, the sky, and most likely the earth below every 2 seconds. The second portion of the OSO is the sail structure, which contains the solar cell power-plant. This is controlled in azimuth to point to about 1 minute of arc to the sun. The third, or pointed section, is controlled in elevation, also to about 1 minute of arc. Instruments, such as X-ray or L_α telescopes or spectrometers, may be placed in this section and pointed at a given spot on the sun with great accuracy. In addition, of course, the satellite is provided with the needed control, command, and data handling facilities. An onboard tape recorder provides nearly continuous information retrieval.

The OSO–I was launched March 7, 1962, into a near circular 550-km orbit of 33° inclination and 95-minute period. Inspection of the data indicated that the cosmic-ray background effects were considerably greater than anticipated and that, in addition, certain completely unanticipated effects were observed. Reducing about 500 quasi-analog magnetic tapes and combining the data with orbit parameters was, of course, found to be a nontrivial problem and is just now being finished in a completely satisfactory manner. In the meantime, the physical effects have been understood, even though all of the data have not been run through the computer for the last time.

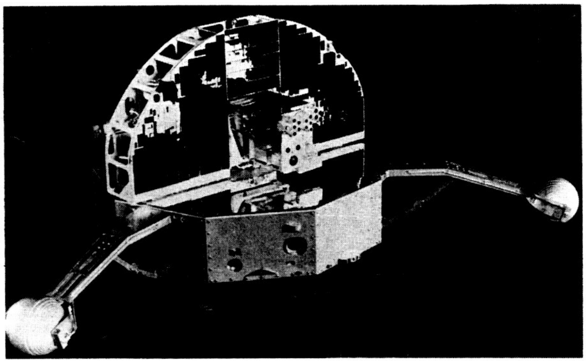

Figure 3.—Photograph of the first OSO. The wheel section spins at about 0.5 rps, with the spin axis constrained to lie in a plane perpendicular to the earth-sun line. The solar cell array is mounted on the sail. Instruments in the pointed section are servo-controlled on the sun to about 1 arc-minute.

Two of the important effects are indicated in figure 4, which shows the rates of the isotropic gamma-ray counter as the satellite crossed the 60° E meridian of longitude. The lower branches of the curves are due to cosmic ray production in the satellite and in the earth below; the upper branches are due to radioactivity induced in the NaI detector during the brief passages of the satellite through the trapped

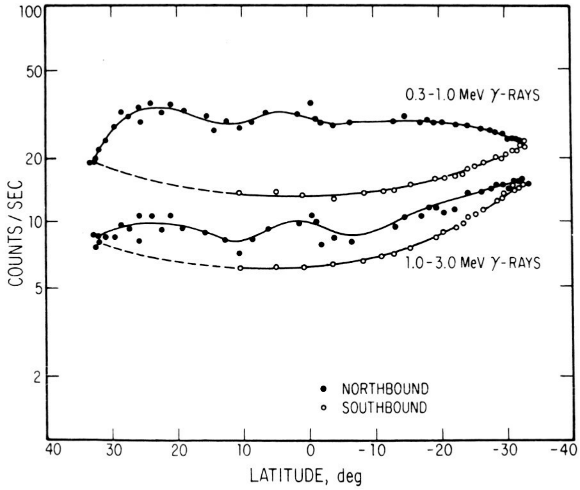

Figure 4.—Rates of the isotropic detectors on the OSO-I, as a function of geographic latitude (60° E. meridian, passes 225–450). The lower curves are due to cosmic-ray effects; the upper curves are due to induced radioactivity in the counters.

radiation over the South Atlantic region. Neutrons are produced by trapped protons which undergo nuclear reactions in the aluminum surface structure of the spacecraft. These neutrons are captured by the I^{127} of the scintillation counters to form I^{128}, which undergoes a β-decay with a 25-minute half-life. This effect has caused considerable complication of the analysis of the OSO-I data and has influenced planning on future missions.

Of course, the most important objective was the search for the extraterrestrial flux. Figure 5 shows the upper limits from this experiment. These limits were obtained from the total counting rate of the isotropic counters over the geomagnetic equator, correcting for a gain change of the detectors and selecting passes where induced radioactivity was not important. Presumably, cosmic-ray effects are minimized in this manner; however, as indicated in figure 4, they are not zero. An extraterrestrial flux would, of course, be latitude independent. Also shown are the fluxes actually measured on the Ranger III, with an isotropic counter on a boom, half-way between the earth and the moon. The two measurements can be reconciled. The lowest energy point of the OSO-I upper limits is not in disagreement with those measured on the

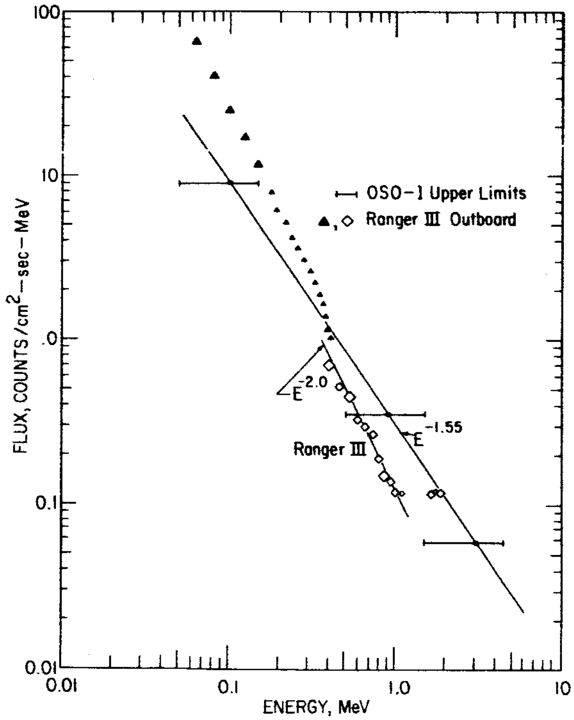

Figure 5.—Upper limits of cosmic gamma-ray fluxes from the OSO-I compared with measurements on the Ranger III. Differential number spectrum, 50 keV to 5 MeV.

Ranger III; the solid angle of the lead-pipe detector on the OSO–I is considerably less than 4π. These fluxes are of course the total, from all sources, both point and diffuse, integrated over 4π solid angle.

BALLOON STUDIES

About the time of launch of the OSO–I it became apparent that knowledge of the cosmic-ray-produced, gamma-ray fluxes was inadequate to intelligently plan and design experiments for cosmic photon measurements in the general energy range of about 10 keV to 10 MeV. Accordingly, a series of balloon investigations were undertaken. A balloon-borne gamma-ray detector above about 110 000 feet is essentially exposed to the same cosmic-ray composition and intensity it will find on a satellite or in space; however, because of interactions in the atmosphere, the gamma-ray background is somewhat worse. The balloon investigations then have two purposes, one of which is to increase basic knowledge of cosmic-ray processes in the atmosphere. This may, of course, shed light on processes on a galactic or cosmic scale. The second purpose is to actually test designs of instruments for X-ray and gamma-ray astronomy. In addition, recent evidence indicates it is possible to observe certain celestial objects from balloons in the light of their X-rays.

One of the early objectives was to interpret the OSO–I results, particularly in respect to the effects of local matter near the scintillation detectors. Accordingly, a number of balloon flights were accomplished. The detectors of a backup instrument were first flown with local instrument matter, such as circuits, magnesium housings, and lead collimators present in the OSO–I flight configuration. Then this matter was removed, and detectors were placed, with their geometry preserved, in a Styrofoam block. Some of the results of this study are shown in figure 6. About 20 percent of the single counter rates on the OSO–I can be attributed to production in the instrument materials. Rates which involved scintillation counters in coincidence decreased by a factor of about 10 when the instrumental material was removed.

Some of the general features of gamma-ray intensities on the earth, in the atmosphere, and in space are also indicated in figure 6. The rates at sea level are due to radioactivity in the rocks and soils. As soon as the balloon leaves the ground, the intensity drops by a factor of about 10; it then increases with the atmospheric cosmic-ray intensity and goes through a transition maximum with the charged cosmic-ray component. At high altitude, the gamma-ray intensity is comparable to that at sea level. The flux in space is apparently

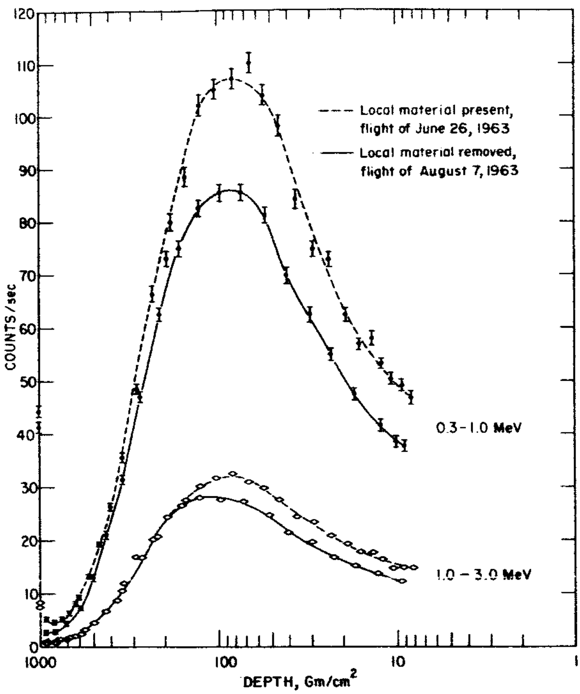

Figure 6.—Total gamma-ray counting rates on the ground and in the atmosphere plotted against depth (λ= 40°). Obtained during a balloon study with the OSO-I detector (Yuma, Arizona). The rates in space are several factors less than those at 6 gm/cm².

several factors below that measured at 110 000 feet on a balloon and much less than that due to local radioactivity of the rocks and soils.

Other measurements have provided information of a more fundamental nature. Figure 7 shows the spectrum at 110 000 feet between about 40 and 700 keV obtained with a NaI crystal and a 16-channel pulse spectrum analyzer. The gamma-ray line at 0.5 MeV was first measured in the atmosphere in these experiments. This line is due to

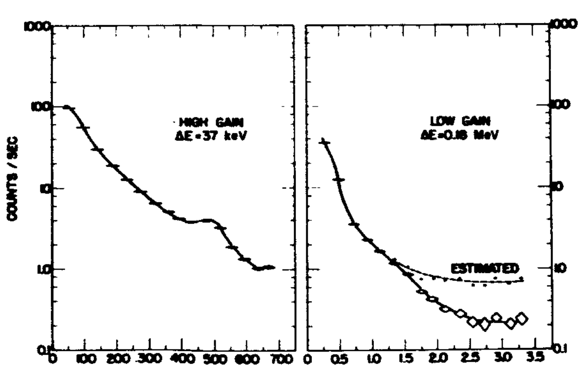

Figure 7.—Gamma-ray spectrum in the atmosphere at 110 000 feet over Minneapolis, Minn. The gamma ray at 0.5 MeV is due to annihilation of cosmic-ray-produced positrons. Differential pulse height spectrum: flight 533, May 2, 1961; 7 bm/cm² depth; G₀= 33 cm².

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positrons, produced by cosmic-ray interactions, stopping and annihilating in the atmosphere.

The exact source of the atmosphere gamma rays at low energy, that is, whether they are produced by electromagnetic process from the soft component of cosmic rays or by low-energy nuclear interactions on atmospheric nuclei, can be determined from the shape of the spectrum between 1 and 10 MeV. Figure 8 shows a simple apparatus, built in collaboration with Dan Schwartz, a graduate student at

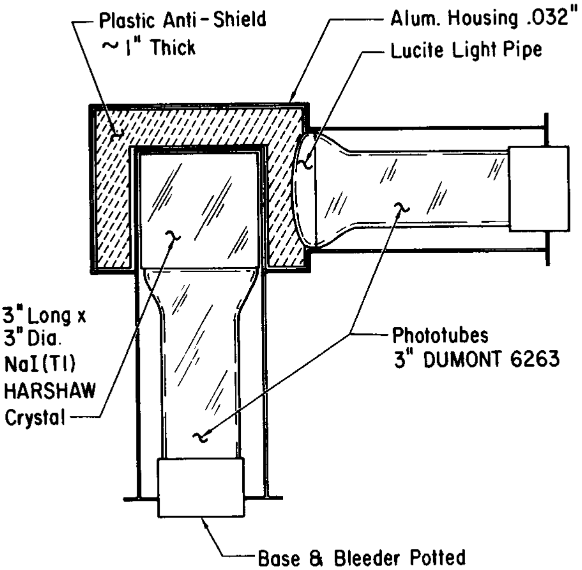

Figure 8.—Simple medium-energy, gamma-ray detector apparatus flown on a balloon to study the gamma-ray spectrum between 1 and 10 MeV.

UCSD. It consists simply of a 3- by 3-inch counter with a plastic anticoincidence shield to reject cosmic rays. The entire apparatus consists of a 128-channel pulse-height analyzer and a telemetry system, and has been flown on balloons twice now. The results of a flight over Yuma, Arizona, to 110 000 feet (6 Gm/cm^2 atmospheric depth) are shown in figure 9. The points on the spectrum between 1 and 10 MeV were obtained in this experiment. Although there is some indication of line structure, clearly the most important component of the spectrum is the steep continuum. This is regarded as evidence that the significant source of lower energy gamma ray is from the degraded products of the soft component. This component has its origin in π° mesons produced in the first few radiation lengths from the top of the atmosphere. Gamma rays produced by nuclear exitation and neutron inelastic scattering and capture would show a definite line structure and would tend to peak at about 6 or 8 MeV. Also shown are measurements made on other flights, and by other workers, to complete the general picture of low-energy gamma rays in the atmosphere.

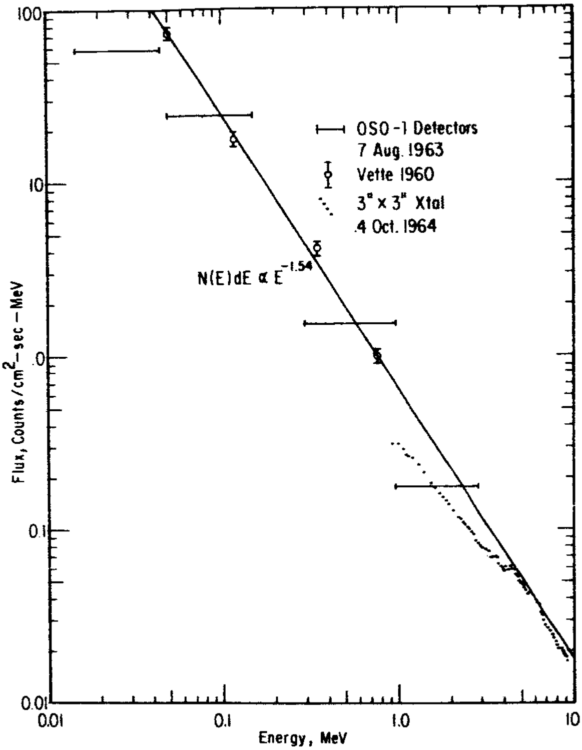

Figure 9.—Photon fluxes obtained over Yuma, Arizona (λ= 40°, 7 gm/cm²). The general steepness of the spectrum and the lack of outstanding line structure between 1 and 10 MeV is taken to indicate most of the atmospheric gamma rays originate in cascade electromagnetic processes.

OSO—III EXPERIMENT

Another result of the balloon work, in collaboration with Ken Frost of the NASA Goddard Space Flight Center, has been the development of an X-ray detector. This detector operates in the region from about 7 keV to 200 keV and is designed for the third OSO. The general block diagram of the detector is shown in figure 10. It is similar to the collimated detector flown on the OSO–I, except for the impor-

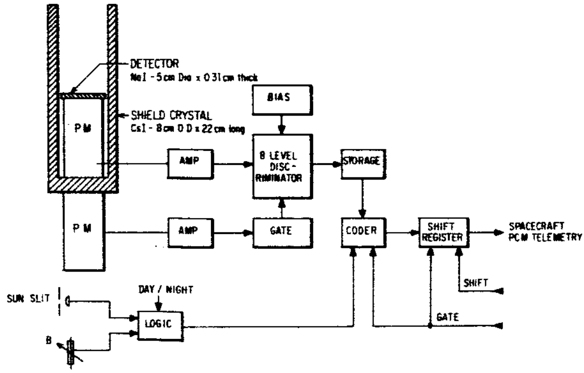

Figure 10.—Block diagram of an S-57 X-ray detector designed for the OSO–III satellite. The active CsI collimator is placed in anticoincidence with the central detector, giving a very low background count.

tant difference that the collimating shield is constructed of CsI, a scintillating material. The shield is then placed in electrical anticoincidence with the central detector. In this way, background effects produced by cosmic rays in the collimator are removed electrically, and one obtains a shield whose rejections is close to the theoretically predicted response. The experiment is limited by phototube noise on the low-energy end and by the finite shield thickness at high energies.

The instrument as constructed for the OSO–III has eight logarithmically spaced differential channels of pulse-height analysis. There is of course a rather elaborate system of storage, coding, direction indication, subcommutation, and signal conditioning associated with the complete instrument. This instrument is, once again, designed to be placed in a wheel compartment of an OSO looking radially outward. This instrument is on the third OSO.

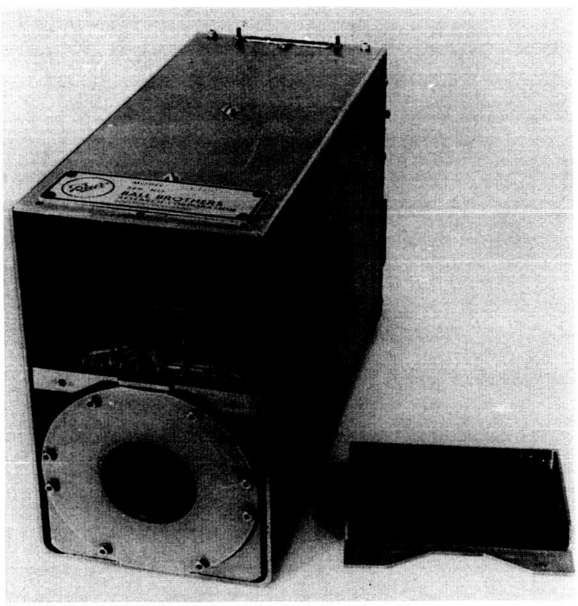

Figure 11.—Photograph of the OSO–III dector. This instrument is also designed to be placed looking radially outward from wheel compartment on OSO satellite.

A photograph of the complete instrument is shown in figure 11. Since there was insufficient technical support available when this project was started, the entire instrument design and construction was subcontracted.

This instrument was flown on a balloon during the breadboard phase to determine its background and to verify the properties of the active anticoincidence collimators. The background determined from this flight, together with the present experimental situation on cosmic fluxes, is indicated in figure 12. Shown is the differential photon spectrum from cosmic sources as a function of energy. About a dozen X-ray sources, generally in the direction of the galactic center, have now been identified at energies of a few kilovolts. These observations, some of which are indicated in the figure, have been obtained from rocket flights by groups at the Naval Research Laboratory, American Science and Engineering, and MIT. Also shown is the flux at about 40 keV measured, by George Clark of MIT, from the Crab Nebulae from a balloon and the results obtained from Ranger III and the OSO–I at higher energies. The rocket and balloon results pertain to single localized point sources, whereas the results at higher energy include all sources, integrated over the total solid angle.

The measured background of the OSO–III detector for point sources as determined at balloon altitudes is also indicated. Most likely at satellite altitudes the background will be less. Clearly, the experiment will provide new and important observations of cosmic X-rays and will contribute to the continually accumulating knowledge in a new and exciting area.

NASA-UNIVERSITY RELATIONS AT UCSD

The nature of the NASA supported experimental program at UCSD calls for some remarks of a nonscientific nature. The situation at the University of Minnesota is rather well known and has been described in some detail in the previous paper by John R. Winckler.

The University of California at San Diego was formed from the Scripps Institution of Oceanography about 6 years ago. It received a considerable impetus under the direction of such men as Roger Revelle, Harold Urey, James Arnold, and Keith Brueckner. Until the fall of 1964 it was only a graduate school. There are now about 400 graduate students. In the fall of 1964, 175 freshmen undergraduates were admitted. This past year Revelle College, of which the Department of Physics is a part, has begun occupying its new and permanent quarters.

Studies of meteorites, cosmic dust, lunar and planetary compositions, and so forth have been carried on for some time by the geochemists and earth science people at UCSD. Space physics, as such, in the Physics Department started about 3 years ago when Carl McIlwain, formerly a student of Van Allen at Iowa, and I arrived at UCSD. McIlwain, whose present main interest is the trapped radiation, and I occupy most of one floor of one wing of the Physics Department. Also located in the same wing are the plasma physicists and the astrophysicists, the groups with which we interact the most.

McIlwain and I now support about 25 people—scientific and technical personnel and graduate students. There are one engineer, a

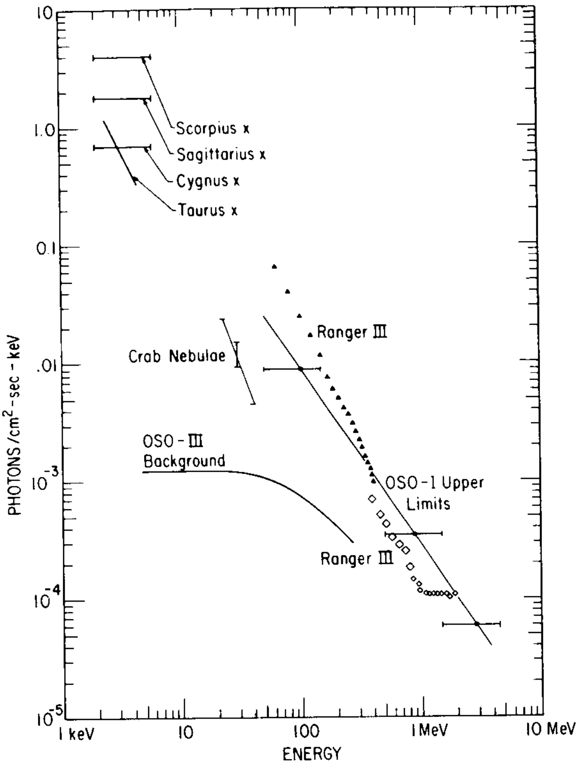

Figure 12.—Differential spectrum of measured cosmic X-ray fluxes (differential number spectrum, 1 keV to 10 MeV). This is compared with the background of the OSO–III detector as measured on a balloon flight. The point sources at low energies were measured on rocket flights. The Crab Nebulae at 40 keV was measured from a balloon. The results at higher energies pertain to the entire 4π solid angle of the sky.

technician, a computer programer, and about four students working on the gamma-ray astronomy projects. McIlwain and I each have sustaining grants from NASA headquarters, as well as hardware and data reduction contracts for specific missions from the NASA Goddard Space Flight Center. We share laboratories and facilities as much as possible.

UCSD does not have an interdisciplinary grant; one is currently being proposed. In terms of general facilities, UCSD has an excellent computer center; the machine shop is about 1 year old and will become quite good after the shakedown is completed. There is no general electronic facility with high-class electronic designers. The electronics are done presently in the Space Physics laboratories at UCSD.

The balloon flights at UCSD were formerly handled by the remains of the Convair group at General Dynamics/Astronautics. This balloon group was abolished last year. A small in-house balloon facility is presently being built. Flights involving large balloons are handled through the facilities of the National Center for Atmospheric Research at Palestine, Texas.

we were able to proceed on a limited basis, and although no actual hardware was constructed, the time was not completely lost. It would seem that some effort should be made on NASA's part to reduce these times.

CONCLUDING REMARKS

A unified program in X-ray and gamma-ray astronomy, in which balloon experiments are used to support satellite missions was presented in this paper. The instrumental techniques used in these studies and the present state of knowledge of X-ray astronomy were indicated. How this program fits into the academic program at UCSD as a whole and, in one case, how an investigator uses staff, students, and facilities in a NASA-supported scientific program were discussed.

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The balloon experiments allow a graduate student to do something fairly quickly at the start and to obtain some results soon. Satellite experiments are admittedly long-term projects and not ideally suited for a graduate student, particularly if followed from experiment conception to final analyses of the data. It seems possible for a student to study the properties of an instrument using balloons, make some related measurements, and then analyze data for a thesis from a mission which used the instrument. Also, it seems possible to work backwards, that is, have a student work on data for an initial cut and then do a balloon experiment, or develop a satellite instrument and use it to obtain some important measurement from a balloon. A student who has only analyzed someone else's data for a thesis has not had a complete education in experimental physics. The use of rockets and balloons in conjunction with satellite experiments adds a considerable degree of flexibility to a graduate space program. Of course, it is not possible to use this combination in every area of research.

Unless a school has a large facility or has many experienced and eager graduate students, it is very difficult for a single investigator to reduce data from previous missions, teach, and have some time to think; at the same time he is concerned about delivering hardware for a specific launch. Under such a situation, a subcontract for the hardware seems appealing and may even be desirable; this situation existed at UCSD 2 years ago.

Of course, the investigator must know all the constraints of the experiment well, as the physical judgments must be made before a subcontractor can start. Even then there is some danger that after 2 years of subcontractor effort, one may be delivered an instrument which managed to meet nearly all the written specifications, but somehow the engineering compromises, or the reliability, are such that the apparatus will not provide the measurements for an imaginative and well-conceived space experiment. In order to retain control over the experiment in our case, we were able to make effective use of the PERT system. PERT, which means Performance Evaluation and Review Technique, is a management method which is used in the OSO program by NASA. Constructed into the PERT chart were approval points, at which times we had to go to the subcontractor, look at the apparatus, perform calibrations, make measurements, observe pulses, or do whatever was appropriate. This allowed an impersonal way of indicating to NASA if the apparatus being constructed by the subcontractor was not satisfactory. Fortunately, in our case, everything was generally all right and relations with the subcontractor were most pleasant; nevertheless, the control existed. About 6 months were required after program approval while NASA, the university, and the subcontractor argued about contractual details. During that time

COMMENTS

***McMillen**, University of Omaha:* Can you tell something about the mechanism of the induced radioactivity you reported in the sodium iodide crystal?

Petersen: Presumably, the mechanism is that protons of the interzone incident on the spacecraft itself produce neutrons. These neutrons are captured by iodine 127 to form iodine 128. Iodine 128 has a half-life of something like 25 minutes. The cross section for capture is rather high, on the order, I think, of 6 barns for thermoneutrons, 1 barn for 100 keV neutrons, and 1/10 barn for 1–MeV neutrons. Of course, one does not expect neutrons to be thermalized within the satellite itself because the total path length is too small.

McMillen: How do you make your distinction between X-rays and gamma rays?

Petersen: I don't make it very rigorously. I didn't intend to in this paper at all. I think I have used the terms rather interchangeably here.

***Tombaugh**, New Mexico State University:* In one diagram showing sources of this radiation, there were four at the top, Scorpius and Saggitarius and so on, which occupied a very different position from the crab nebulae radiation. To what do you attribute this great difference?

Petersen: The sources in Saggitarius and Scorpius have not yet been isolated in terms of visible object being identified with these sources. Presumably their mechanisms are somewhat different from those of the crab nebulae. No one really understands in detail the mechanisms for producing these X-rays yet but, presumably, it must be either remstrohn or syncotron radiation of very high energies. These sources are not at all understood by astrophysicists.

Tombaugh: Couldn't graduate students have been used on some of this work for Ph. D. theses?

Petersen: Once again the problem is that from the conception of an experiment until its execution and the analysis of the data a rather long time is involved; however we are trying tentatively to have students initiate their experimental work during balloon flights, exploratory work, and so forth, and presumably, then they can write their Ph. D. thesis on either the analysis of data which are obtained from an instrument similar to one on which they did their work or from some problem which develops from the balloon studies. It seems essential to have a fairly continuing program, requiring a satellite launch with an instrument on it periodically in order to keep momentum going and to provide continuous series of results and data.

Exploitation of Space Environment for Biological Research

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THIS PAPER CONCERNS my experiences as an experimenter participating in the NASA Biosatellite Program, not an easy subject because I cannot describe the results of a flight experiment which has not yet been flown. The first Biosatellite of the programed series literally has not gotten off the ground. I can only review briefly the program as I see it, and try to give some impressions of what it is like for a biologist to be involved with a program of this kind. I also may be able to identify some of the difficulties which I or other biologists have encountered.

I feel a rather strong intellectual commitment to the Biosatellite Program simply because I have watched it develop all the way from the concept to the hardware stage. I naturally have a parochial interest as a biologist and as an experimenter in this program.

The scientific objectives of the program really are to exploit rather than to explore. By "exploit" I mean to use those features of the space environment which make it possible to perform biological experiments which can be performed only in space. That better publicized aspect of space biology—searching for and studying exotic life which may exist in space, on the Moon, or on other planets--is a quite different topic which I shall not discuss here.

The operational part of the Biosatellite Program involves a series of six recoverable automated space platforms, that is, space laboratories. These wil be unmanned, and they will be flown for varying periods. The first flight will probably occur in the spring of 1966 and subsequent flights will follow at 3- to 6-month intervals. Such a satellite will carry one to several biological experiments.

What makes these space laboratories unique? What are the reasons germane to biologists which justify performing this series of inconvenient and expensive experiments which must employ difficult techniques so foreign to the experience of most biologists? The principal reason as far as my own experimental interests are concerned is that the satellite can provide a gravitational field which is not equal to unity and it can do this for extended periods. Specifically it can furnish gravitational fields between approximately zero and unity. For long-duration experiments such fields cannot be obtained here on Earth. Weightlessness is approximated by an object in Earth orbit but also by putting a centrifuge on board, one can obtain gravitational values even in excess of 1 gravity. Thus one can extend to a range of gravity which is available as an experimental variable.

Of course, the Earth's gravitational field extends into space and it is not quite correct to refer to an Earth satellite as a place where there is no gravity. So-called "zero gravity" is perhaps better termed *weightlessness* for being in orbit is the equivalent of free fall rather than the absence of gravity. Weightlessness is only the lower extreme of the range of gravity which is available for space experiments in biology, but because this lower limit is generally considered to be the most interesting condition for early investigation, its effects will be the first to be explored. None of the Biosatellites in this present program will have a centrifuge on board.

A second feature of a space vehicle which is of specific biological interest is the apparent disconnection of the experimental material from the Earth's rotation. In a satellite orbiting the Earth every hour and a half periodicities which may be related to encircling the Earth will depart very far from the nearly 24-hour periodicities which are so common in all kinds of biological materials. The wide diversity of rhythmic phenomena remain in a very fundamental sense a mystery and a challenge for we do not understand the biological driving and control of mechanisms which regulate these ubiquitous rhythms and endow them with some remarkable properties. Studies of such rhythmic phenomena in orbit will reduce the likelihood of influence by factors connected with the Earth's rotation.

These two features, one relating to gravitational forces, the other to rhythmic phenomena, account for the desire of biologists to use satellite laboratories. Aside from the opportunities to carry out unique experiments there are still other features of the Biosatellite Program which for most biologists make it unusual if not unique. It is an example of team research on a scale usually encountered only in such things as, say Antarctic expeditions, where many hundreds of people have intricately dependent roles to play in making the experiments or observations successful. Also it is of necessity a multidisciplinary activity and the biologist cannot hope to master intellectually, or even to be aware of many aspects of the total operation. Then too it involves a very heavy overlay of engineering with which many biologists are not conversant. A final point is the high cost per experiment. Costs impress biologists too and using satellites is a very expensive way to do research. Another way of looking at a high-cost experiment is to recognize the large amount of work that must go into getting relatively little information. I am impressed not only by the high cost as such but even more by the realization that a very substantial commitment of my own time and that of some of my biological colleagues is being diverted from other pursuits in order to engage in this program. Thus we have to be convinced that the results we hope to obtain will be of sufficient potential scientific interest to be ample reward for all the effort.

Turning now to the program itself, there are three phases. The first phase, represented by the first two flights, will attempt to detect a synergistic effect between weightlessness and radiation exposure. Actually the null hypothesis is that synergism will be absent. This I hasten to point out is *not* a test of effects of space radiation on biological materials. The designed orbit will keep all the Biosatellites well below the Van Allen belts and the radiation will come from an on-board source. Strontium 85, somewhat over 1 curie of it, will deliver radiation exposure of the order of a few hundred up to about 5000 roentgens. Since the intent is to avoid space radiation exposure the biological specimens will be expected to react to the doses they receive just as they would on the ground. The difference will be that they are in orbit; they are weightless. Controls will be both on the ground and behind a radiation shield in the Biosatellite. Exposure will be for 3 days. All biological materials which have succeeded in getting on board the flights are those which have been very well studied, that is, whose radiation response in the range of the designed exposures is well understood. If the responses are not those expected, differences will be detected quantitatively and reliably. There is a possibility that weightlessness can in some way influence the response of an organism to the stress of ionizing radiation. Antagonistic or synergistic effects are not anticipated but could occur. In the absence of any experimental evidence it would be presumptive to argue that radiation response could not possibly show a gravity-dependent component. If none is observed, an impressive body of information on radiation effects can be extrapolated confidently into space environment situations. Our wealth of Earth-bound predictions of radiation tolerances will be a much more useful legacy to the space science required for manned missions in space if we can be certain the extrapolation is fully warranted. The matter thus has also a very practical importance.

The experiments selected for what I have called the first phase of the program range over both plant and animal kingdoms from lower to higher forms. Each choice of experimental organism was based on its suitability for quantitative evaluation of some radiation effect in the dose range to be administered. A number of different kinds of effects are to be investigated.

If, as I now believe unlikely, any organism's radiation response should exhibit a gravity-dependent component. This would be a discovery of great import. Surely follow-on experiments would have very great scientific interest as well as tremendous practical importance.

A second phase of the program, represented mainly by the third and fifth flights, will include experiments on plant morphogenesis as well as observations of the rhythmic behavior of plant and animal materials. These experiments will be flown for 3 weeks. In general morphogenic effects of weightlessness merit attention chiefly because we do not understand how the organism's gravity sensor operates. Research on morphogenesis with respect to the gravity variable is now only in an advanced exploratory stage. The expectation is that weightlessness will quite certainly introduce some abnormalities, and by examination of its effects at different levels of biological organization, we may expect to find clues to help us work out mechanisms for these gravitational influences.

Most organisms detect the direction and strength of the gravitational acceleration to which they are exposed. They respond to the gravity field in the course of their development and in their behavior. In many instances, the mechanism by which the organism senses acceleration is incompletely known. This is especially true in the case of the higher land plants.

From what we know in general about sensory physiology in animals and plants, we can expect some part of the sensing mechanism to be observable morphologically. Perception of gravity in most organisms is identifiable only in terms of certain kinds of responses, the nature of which depends on the species under observation. Response modes (especially in animals) may include balance, spatial orientation, locomotion, communication, or navigation, depending on the organism. Morphological responses (especially in plants) in growth pattern, establishment of polarity and symmetry, and the time course of development are well recognized responses to the gravitational vector in many cases.

Morphological changes attributable to altered gravity may be expected at any level of organization. While gross changes in macroscopic growth form surely must occur under conditions of abnormal gravity, subcellular or microscopic changes also may be especially significant for our improved understanding of the gravity-sensing mechanism of higher plants.

In higher animals, including primates, some possible indirect consequences of altered gravity may be expected from drastically altered peripheral stimulation and may include atrophy of certain tissues or organ systems. The practical consequences of the latter effects are of obvious significance for manned space missions of long duration.

In previous studies of the gravitational responses in higher plants, the environmental biologist has been at a disadvantage because what probably will prove to be the most interesting range of the gravitational variable has not yet been explored. The opportunity to make this exploration naturally is exciting, the more so because the plant physiologist simply cannot make confident predictions of plant behavior in situations not previously examined when that behavior depends on one or more sensing mechanisms, which are themselves not understood. Inevitably, progress will await the acquisition of purely descriptive data. My own interests as an experimenter lie in this phase of the program. I shall describe our experiment later.

Phase III, if I may call it that, will be a study of primate physiology which will involve the fourth and sixth flights. These will be 30-day flights. Since the monkey along with accessory equipment will take up all of the payload, only one experimental organism can be used. A series of observations will be made on the monkey. He will have deep brain probes, and certain cardiovascular and urinary data will be acquired. Neurophysiologic, circulatory, and behavioral characteristics of the primate are expected to be altered by prolonged weightlessness. While the application of test results to manned space missions is not the principal scientific motivation for this part of the Biosatellite Program, it nevertheless is sure to be an important by-product.

Experiments on biorhythms will be included on both the 3-day and the 21-day flights. Let me say a few words about the rationale of these tests. Physiological rhythms in a wide range of organisms have been demonstrated repeatedly, and it now is generally appreciated that such phenomena are practically universal. The most prominent frequency component in most plants and animals approximates 1 cycle per day. Since diurnal fluctuations in the terrestrial environment always can influence the phase of a particular rhythmic process, it may be that the fundamental oscillation responsible for these rhythms lies in the environment rather that within the organism. However, many diverse, and often very elaborate, attempts have been made to isolate tests organisms in the laboratory from temporal clues based on light, temperature, atmospheric pressure and composition, sound, cosmic radiation, and other factors which show cyclic changes and which, if sensed by the organism, could conceivably be responsible for the rhythms exhibited by so many biological processes. Since rhythmic phenomena persist in organisms presumably well isolated, two divergent schools of investigators attribute the observed rhythms in the one case to strictly endogenous processes and in the other case to fluctuating environmental influences somehow related to the Earth's rotation—in other words, the test organism is assumed *not* to be effectively isolated from some factor which cannot unfortunately be identified but which has defied previous attempts to eliminate it.

The difference in these viewpoints is fundamental, and fortunately it can be resolved by experiment. We must remove the test organism from influences of the Earth's rotation, and this can be done in space. Our first attempts can be made in near-Earth orbit, and such tests will be included in the present series of biosatellites. However, if that approximation proves insufficient and if we then have to remove the experiments completely from the Earth's influence, we may need to conduct later tests at least 50 000 or 100 000 miles from the Earth.

Now, as for my own personal involvement as an experimenter. I have two colleagues now working with me at the University of Pennsylvania—A. O. Dahl, a cytologist (now on leave from the University of Minnesota), and Lars Loercher, a plant physiologist. Ground-based work in preparation for the flight is underway both in my laboratory and at the NASA Ames Research Center, where K. Yokayama, a plant biochemist, has a position of special responsibility in connection with the flight hardware as well as being involved with biological aspects of the experiments.

Our experiment like all the others will be launched from Cape Kennedy in a 200-nautical-mile orbit. Capsule recovery will be attempted 3 weeks later in the vicinity of Hawaii by "air snatch." Sea recovery is less certain and takes longer so we plan hopefully on the air recovery being again successful.

Our test organism is a small flowering plant which goes by the name *Arabidopsis thaliana.* It has no good common name but, if you wish, you might call it European wall cress. It is in the mustard family. Its special advantages are that it does not occupy much space and it completes its life cycle in a very short time. It grows from a germinating seed to a mature plant, flowers, and sets seed all in about 3 weeks. Think of *Arabidopsis* as a little plant in a hurry.

We are growing *Arabidopsis* plants in small chambers on nutrient agar in the laboratory. We are standardizing on growth conditions (viz., temperature, light intensity, etc.) which are those specified for the flight experiment. We are learning as much as we can about the way this plant grows under the specified conditions, and by this I mean the quantitative and qualitative features of its pattern of development. Growth and development studies are underway at different levels of organization: from the gross morphology of the whole plant down to subcellular structures. Without going into tedious detail I think one can appreciate that the time course of development of any complicated structure like an *Arabidopsis* plant can be broken down into numerous components or "markers" and measured in suitable, quantitative terms. Broadly speaking, the integration of all such component measurements constitute a description of the growth of this plant. The precision with which growth can be described naturally depends on our ability to select appropriate markers and it is important that we choose for measurement those which lend themselves most readily to quantitative measurement and which prove to be reproducible.

We intend, of course, to make comparable measurements on *Arabidopsis* plants growing in a weightless state and I'm sure it is obvious that we are assembling what you might call control data. But we are making still another comparison; we are growing plants in a condition that I shall call simulated weightlessness on a type of apparatus long familiar to botanists called a clinostat. Let me explain how this works.

Most plants are remarkably sensitive to gravity and will respond to gravitational fields perhaps even as low as 1 micro-gravity. The threshold of sensitivity has been studied indirectly by several quite different methods in other laboratories. However, in spite of the high sensitivity, comparable it seems to nonbiological accelerometers, the test organism does not respond to a lot of stimulus unless it is presented for a rather long time, a time measured in many tens of seconds to a few minutes for a field of 1 gravity and correspondingly longer for lower accelerations. A fairly long stimulus "presentation time" is required to elicit a response from the plant. The type of response I refer to is shown by the following simple experiment. Place a growing plant in a horizontal position and after an appreciable latent period it will grow in such a way as to reorient itself in an upright direction of shoot growth. If the plant is turned upright after only a few seconds in the horizontal position no bending response occurs; the plant did not respond to its brief reorientation. With longer exposures however one can observe a bending response. Thus it is possible, because of the rather long minimal presentation time for a response to reorientation in the Earth's field, to keep a plant growing in a horizontal direction by slowly rotating it on its long axis while it remains horizontal. The clinostat is simply a turntable which rotates the plant fast enough so it has not the chance to respond by growth in any one lateral direction yet which does not rotate the plant so fast that centrifugal force becomes significant. Rotation rates on the order of 1 rpm are satisfactory.

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Such clinostat grown plants are not normal but they are nearly so in many respects. They have altered growth rate, reduced sensitivity to certain environmental stimuli, a somewhat changed morphological pattern, and can be distinguished easily from control plants. In an imperfect sense of the term we can refer to clinostat grown plants as having grown under simulated weightlessness. So we should have three kinds of plants for intercomparison: (1) the normal (1 gravity) plants, (2) the clinostat grown plants, and (3) the satellite grown plants where weightlessness will be actual not just simulated.

Flight data will be collected in two ways. Gross morphological information will be obtained by time lapse photography. Two cameras will view a series of culture chambers containing the plants and store the information on film. Recovery of the capsule is therefore essential for, even though the experimental design originally called for telemetry of the photographic information, the engineers were unable to meet that requirement within the resources available.

Anatomical and cytological data will be obtained by fixing the experimental material as soon as we can have access to the recovered flight package and by subsequent imbedding, sectioning, slide making, and microscopic examination.

When we have measured the various markers in *Arabidopsis* plants grown under all three conditions, we should be able to tell wherein gravity influences the course and end products of growth in this species. We should know how well the condition of a clinostat simulate true weightlessness. We should know what markers are little affected by gravity and which are ripe for further study. This investigation is obviously exploratory and possibly preliminary to more intensive examination of gravity-effects on specific markers which would lead to improved understanding of the plant's mechanisms for sensing the strength and direction of the gravitational force and for using the information to guide its growth.

Of the difficulties which beset an experimenter involved with a program of this kind, I have a short list of problems, criticisms, or difficulties which I can recognize as important in limiting the successful involvement of biologists in the space program. I offer them without elaborate comment. First is one, emphasized in previous papers, which I fear cannot be helped—the very long lead time which is involved in an experiment in a satellite. This I believe makes it essentially unwise if not impossible for a graduate student to do a thesis which depends on a flight experiment.

Second is the unfamiliarity of most biologists with the engineering aspects of a satellite operation. For the biologist who seriously contemplates a flight experiment, there is an investment of a lot of his time learning, if only in a superficial way, a lot of engineering details. Many scientists have been unwilling to invest this time.

Third, there have been frustrating experiences when biologists have attempted "piggy-back" rides on vehicles which were flown for other purposes. These experiences have been so unfavorable that this has left a very general bad impression of piggy-back rides for biological experiments. Rightly or wrongly, this makes most of my colleagues unwilling to submit proposals for a vehicle whose principal mission is nonbiological.

The overriding demand that schedules be met is another difficulty. Of course, this requirement is essential for it would be characteristic of any large and complex operation. One is accustomed to a kind of freedom to proceed with less than full commitment to a particular approach, to discover better ways to do something or better experiments to perform, and to change plans when this would be the intelligent thing to do. The necessary limitation on one's freedom to alter even fairly trivial details of methodology is not readily accepted by a scientist who is used to a rather different approach.

Also, a scientist with a good idea and perhaps interested in proposing a space experiment or two may be isolated from adequate engineering competence. If he works in an environment which cannot offer the needed engineering help, he is dissuaded from making a proposal. Even if he does so and finds out later the engineering facilities and personnel at his institution are not enough for the job he wants to do, he is apt to spend many frustrating hours lining up such help elsewhere. Modern biology is not so well geared for getting the most out of space laboratories.

Then there is the reduction, sometimes I believe an unnecessary reduction, of the experimenter's responsibility for his own experiment. Efforts to combat this have not always been effective. There are decisions which are properly made only by the experimenter himself. But once the experimenter is part of a team, as he must be, some of these decisions may be made by others or just by default where, because of the experimenter's ignorance or for other reasons, the decision making is out of his hands. This is an ever present danger to the scientific objectives of a program, and it represents a problem which NASA cannot expect to solve, only minimize.

I should like to comment also about the Ames Research Center. This is NASA's in-house center for fundamental biological research. The Ames center should be a research institution to which NASA could point with pride as a biological research institute in the same class as those institutions with which it is naturally compared—the Oak Ridge, Beltsville, or National Institutes of Health laboratories, which are older as centers of biological research and which have biologically similar though admittedly different basic missions. The Ames center simply has not yet acquired biological prestige comparable with these other institutions. I mention this not as an accusation, but just as an observation. If NASA had somehow been able to develop at Ames a biological research establishment of great distinction, in many direct and indirect ways this would enhance its potential as a laboratory responsible for a Biosatellite Program.

One last problem relates to the image of space research in biology. There has been and, to an uncomfortable degree, I feel there still exists an unfavorable image of space research among many biologists. A great deal of what is labeled space biology is not fundamental science at all. Yet some apologists for the field do not make fine distinctions and seem to promise more by way of fundamental scientific progress than clearly is possible. There are only a limited number of scientific areas where biologists can expect to derive substantial benefits from space research. These are easily defined significant advances and in these areas remain exciting possibilities. There is no need to overstate the potential here. I believe it is only a question of time before space biology will lose its special designation and will be looked upon, for the most part, simply as biology. I think we shall see this kind of acceptance as the results of space research appear in conventional biological journals. This alone will bring about an important improvement in the image of this kind of biological research. The current Biosatellite Program offers opportunities for such improvement.

IQSY Rocket Studies of the C, D, and E Regions of the Ionosphere

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I WOULD LIKE TO DESCRIBE A SMALL, SELF-CONTAINED PROGRAM of upper atmosphere investigation using rockets. This program may be of some interest in that it was started from a zero level of effort about 18 months ago without any investment in fixed facilities and with a minimum of formal organization.

The concept of the program arose from a strong interest in the physical and chemical processes taking place in the lower ionosphere, or, as we would say, in the aeronomy of the upper atmosphere below a height of 160 km. This is the region which is inaccessible both to satellites and to balloons, and which is therefore particularly suited to study by sounding rockets.

Solar-terrestrial effects associated with sunspots, such as sudden ionosphere disturbances, magnetic storms, and solar proton event's, affect primarily the lower ionosphere, making it difficult to compare rocket measurements made at different times and locations. The current solar minimum period, designated as the International Quiet Sun Years (IQSY), offers an unparalleled opportunity, therefore, to make careful studies of the lower ionosphere in a coordinated way.

As of the year 1962, rocket measurements had given some understanding of the nature of the E-region. This region at heights from 90 to 160 km shows a prominent maximum of electron density during the day, the normal E-layer, at about 110 km; this layer, which is produced primarily by a balance between photoionization and dissociative recombination, becomes much less dense at night and develops a curious layered structure known as sporadic-E. The night curves, incidentally, are not accurate representations of the electron density below a height of 100 km.

The principal uncertainty in these curves lies in the height range below 90 km, where even in daytime the electron density is less than 10^6 cm^{-3}. However, the electrons at a height between 70 and 90 km, in the D-region, are very important because of their effect on broadcast communications; they produce the daytime absorption of ionospherically reflected radio waves.

A further region of the ionosphere has recently attained considerable importance. Situated at an altitude between about 40 and 70 km, it is distinguished by an ionization production rate, presumably due to galactic cosmic rays, which is independent of solar zenith angle. It is also the region responsible for the presunrise ionospheric effects noted in very low frequency radio propagation. Adopting the standard type of rotation used in characterizing the other ionospheric regions, this may best be described as the C-region.

Although a number of groups were engaged before the IQSY in rocket measurements of the lower ionosphere, most of them were interested primarily in the development of new techniques for aeronomic measurements rather than in the use of these techniques, in combination, to solve specific aeronomic problems. It was therefore decided to develop an integrated program in which a basic set of well-tried experiments would be combined on a rocket payload, to be designed in such a way that it could be used repeatedly under a wide variety of ionospheric conditions to answer specific questions about the behavior of the upper atmosphere.

This general aim was presented to the Committee on Space Research (COSPAR) and was endorsed by that organization as a formal resolution; Homer Newell of NASA later indicated that the United States might very appropriately develop a program of this kind.

It was then necessary to decide on the role which a university should play in such a program. Since the primary function of university research is graduate education, the University of Illinois became involved only in aspects of the program in which graduate students could play an active part; and the experiments were developed in cooperation with others in industry and in universities who already had competence in particular areas relevant to the program. Rather than contracting out the hardware aspects, however, emphasis was placed on the scientific involvement of at least one individual in each cooperating institution; and it was agreed that although results would be shared freely, the publication would be carried out by the individual groups. This policy has worked very successfully thus far.

In the design of the payload, the following criteria were kept in mind:

(1) Aerodynamic cleanliness of payload.
(2) Compatibility of the experiments.

(3) Simplicity of the rocket instrumentation.

It was found difficult to fulfill all the desired criteria with a single version of the payload, so two slightly different arrangements were developed. The experiments carried in the Type A payload are shown in table I.

Table I

Experiment	Characteristic measured	Physical parameter
Radio	Faraday rotation	Electron density
	Standing wave	Electron density
	Differential absorption	Collision frequency
dc probe	Electron current	Electron density
	Ion current	Positive ion density
	Current curve	Electron temperature
1216 Å photometer.	Lyman-alpha intensity	Ionizing flux
		Molecular oxygen density.
1450 Å photometer.	Ultraviolet intensity	Molecular oxygen density.
Optical sensor	Solar aspect	
Magnetic sensor	Roll and yaw	
Baroswitch	Approximate trajectory	

The radio experiment is a new modification of the Seddon-Jackson radio propagation technique, which will be described in detail subsequently in this paper. The dc probe is an insulated portion of the nose of the rocket and has a dc potential applied to it; the current which flows to the probe is measured and telemetered to the ground. This latter experiment was developed by Dr. L. G. Smith of the GCA Corporation, Bedford, Mass.

The ambient and integrated ionization measurements described are accompanied by two ultraviolet radiation sensors, the purpose of which is to determine the molecular oxygen concentration in a height range of 70 to 130 km by extinction densitometry. Magnetic and optical aspect sensors are carried. A baroswitch is used as a backup in the event of total failure of radar tracking, using the time of flight of the rocket under near-vacuum conditions to determine the rocket altitude as a function of time with an accuracy of about 0.5 km.

The principle of the radio measurement of electron density is a comparison of the difference in attenuation coefficients (differential absorption) and phase velocities (Faraday rotation) of the ordinary and extraordinary magnetoionic components, at a frequency in the range of 2 to 4 Mc/s. At medium latitudes these polarizations are nearly circular, and the extraordinary is much more heavily absorbed than the ordinary at low altitudes in the C- and D-regions. If a combination of these two polarizations is radiated vertically from the ground, therefore, with the ordinary polarization predominating, a resultant elliptical polarization is obtained, which becomes more nearly circular due to differential absorption as the wave enters the ionosphere.

The experimental arrangement is to radiate the ordinary and extraordinary polarizations from the ground on frequencies differing by 500 cps, thereby generating a polarization ellipse spinning at a rate of 250 rps, and to detect the axial ratio of this ellipse with a magnetic dipole antenna in the rocket, connected to a fixed-frequency receiver. The audio output of the receiver is a 500-cps signal which is telemetered to the ground. The effect of differential absorption on this telemetered signal would be to decrease the amplitude of the 500-cps signal as the ellipse approaches circularity. However, it is used as a feed-back signal to control an attenuator which sets the power radiated from the ground in the extraordinary mode to keep the ellipse axial ratio constant at the rocket. The attenuator setting is therefore a direct measure of the differential absorption due to the ionosphere, and the rocket instrumentation is used primarily as a null detector.

Without going into further detail about this experiment, the following parameters can be obtained from it:

(1) Differential absorption with 0.2-dB accuracy from 0 to 25 dB, up to the extraordinary wave reflection height.

(2) Faraday rotation with 1° accuracy over the total range, which may exceed 5000° (depending on ionospheric conditions), up to the extraordinary wave reflection height.

(3) Ordinary wave refractive index from the standing-wave pattern, with 0.05 accuracy, between the reflection heights of the extraordinary and the ordinary waves.

(4) Z-mode refractive index with 0.05 accuracy between the reflection heights of the ordinary and the Z-mode.

In combination, these measurements suffice to determine the electron density over a range of electron densities exceeding 10 to 10^5 cm^{-3}. An example of the results is shown in figure 1, for Nike-Apache 14.143, launched at 1600 EST on April 16, 1964, at Wallops Island, Va. This was the first Type A payload fired. Figure 2 shows the electron collision frequency (the thick line) deduced from this flight, compared with some other measurements.

Figure 3 illustrates a comparison of the measured electron density from the radio experiment with the electron current measured simultaneously by the dc probe kept at 2.7 V relative to the rocket body.

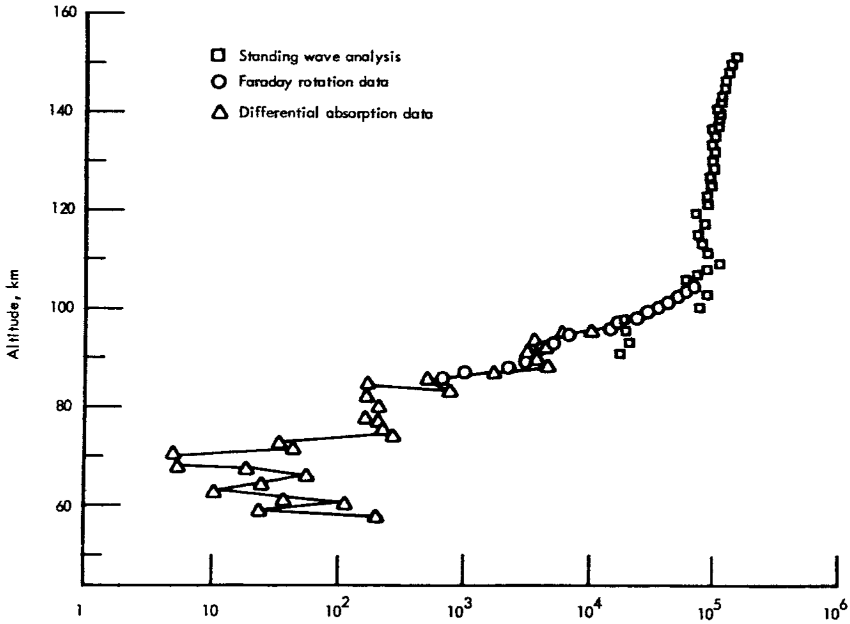

Figure 1.—Electron density cm⁻³.

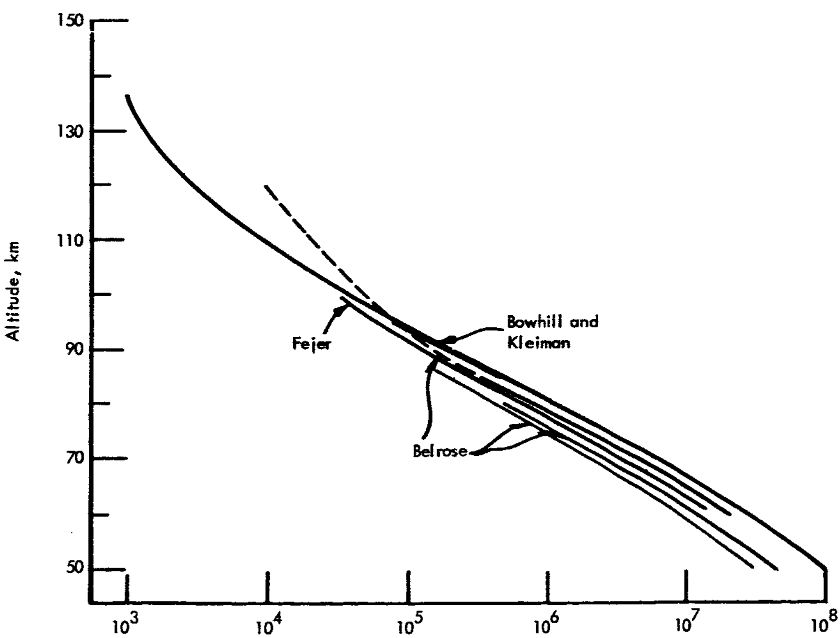

Figure 2.—Collision frequency, sec^{-1}.

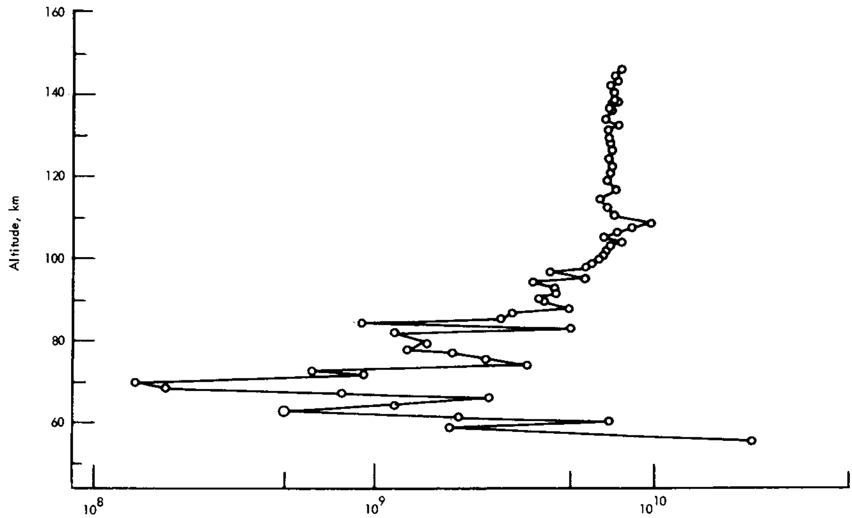

Figure 3.—Electron density/Electron current, cm^{-3} amp^{-1}.

If the simple Langmuir theory of electron collection applies, the ratio of electron density to electron current should be constant with altitude; evidently, this is a good approximation only above an altitude of 100 km. Nevertheless, the dc probe information gives height resolution better than 100 m and makes an ideal companion experiment to the radio technique, which has excellent absolute accuracy but poor height resolution (about 1 km).

SUMMARY OF RESULTS

The payload, discussed herein which appears to work reliably, has been used in a series of geophysical investigations, the results of which may be summarized as follows:

(1) A series of three firings around sunrise in July 1964 demonstrated that the presunrise C-layer (at a height of about 60 km) is produced by photodetachment of negative ions not by visible light, but by light shadowed by the ozonosphere (less than 3000 Å wavelength). This rules out negative ions of molecular and atomic oxygen as constituents of the night C-region.

(2) A firing at sunrise in November 1964 confirmed that this effect occurs at the same solar zenith angle independent of season.

(3) Two firings around sunset in November 1964 showed that the disappearance of the C-layer at sunset is within a few minutes of the same solar zenith angle at which it appears at sunrise.

(4) These firings further confirm that the D-region ionization between a height of 70 and 90 km does not appear until solar Lyman-alpha radiation has penetrated to this region.

Further investigations which will be pursued during the next months include studies of the geographic variations of the lower ionosphere, the nature of D-region irregularities, and the correlation of electron densities and temperatures measured by rockets with those measured by an incoherent scatter technique.

Rocket experimentation has several desirable aspects for carrying out of simple experimentation. First, the time and place of the firing are completely under the experimenter's control; second, very elaborate ground facilities are not needed; and, third, and perhaps most important, there is a relatively short feedback time in the sense that the experimental plans for one firing can be changed based on a quick look at the results of a previous flight made perhaps less than an hour before.

In summary, therefore, it seems that the complexity of the theoretical problems of the lower ionosphere, and our present paucity of good experimental data, makes it a particularly fruitful field for simple experiments which can be devised and implemented by university research groups.

Session V—Technology Utilization

***Chairman:* George L. Simpson, Jr.**
Assistant Deputy Administrator, NASA

Coordinator: W. A. Greene
Office of Grants and Research Contracts, NASA

The First NASA Regional Techonology Utilization Program—A 3-Year Report

Charles Kimball

PRESIDENT, MIDWEST RESEARCH INSTITUTE

THE FIRST MAJOR REGIONAL TECHNOLOGY UTILIZATION PROGRAM sponsored by NASA, which is now in its third year, has produced some unusual results, both in quality and kind, and from this experiment have emerged some interesting findings.

From the very beginning, it was apparent that NASA's primary output is knowledge—an enormous amount, growing at a rapid rate. It has been characterized as one of the great scientific endeavors in history. The Space Act which established NASA in 1958 charges this agency with the responsibility of securing the most effective use of the scientific and engineering resources of the country, and with providing for the widest practical dissemination of information about the benefits to be gained from the use of space activities for peaceful and scientific purposes.

In August of 1961 the National Aeronautics and Space Administration asked the Midwest Research Institute to undertake a two-part pilot study program for NASA in six Midwestern states—Kansas, Missouri, Iowa, Nebraska, Arkansas, and Oklahoma. The Institute's task was to stimulate the educational, industrial, and economic potential of this region through greater participation in space science and technology.

The Midwest Research Institute began in the fall of 1961 with a comprehensive study of 15 leading universities in this six-state region. Each campus was visited in order to look at these universities from NASA's point of view and to help evaluate the school's opportunities for growth in NASA-related areas. The presidents of the 15 universities, many of whom are Midwest Research Trustees, gave the program their wholehearted support and appointed senior faculty members to act as MRI's point of contact with the individual university.

Between October 1961 and March 1962, the MRI team spent 1 or 2 days at each school discussing the NASA programs with appropriate university people. This team briefed the faculties and looked at facilities for research and instruction. A total of 450 administration and faculty members were so involved. In each case, the university prepared an analysis of its own capabilities, sometimes quite extensive and well documented, which was combined with the observations of the MRI team in a report to NASA. Each university was also furnished copies of the report for its own use.

A number of problems were identified during the course of the MRI program. Relatively few scholars were then aware of the scope of NASA interest in science or in the support available, even in universities which already had large programs sponsored either by NASA or other major government agencies. Where teaching loads or existing research already occupied a great part of a department's time and effort, there was sometimes little interest in NASA's program.

The important university role in NASA's research, that of identifying problem areas where an extension of fundamental knowledge is relevant, proved to be a difficult conceptual problem for some universities and scholars, who were more accustomed to working in previously well-defined problem areas. When MRI began its program in the fall of 1961, only 4 of the 15 universities were involved in NASA programs. Today only 2 are not involved. The success of the pilot operation with the initial 15 universities led to a continuation of MRI's work with 17 institutions in the Southeastern region of the United States.

The second and larger part of the NASA assignment has dealt with the industrial utilization of technology developed and used in the space program. One reason MRI was chosen for this pilot effort is that for the past 20 years the institute has been transferring the results of its contract research and technology to 1000 corporate clients, large and small, and to some 200 public agencies. This is an arena in which transfer must meet the test of effectiveness, or the research itself will be prejudiced and, in many cases, useless. For these reasons, MRI knows, and is known, by hundreds of Midwestern companies and businessmen who were the logical initial targets of technology utilization.

The Midwest Research Institute project began with a series of MRI briefings for some 2500 persons in over 20 Midwestern cities. In several of these, the institute worked closely with a university; for example, the meetings with St. Louis, Mo., industrialists were held at Washington University, and St. Louis University and Washington University were the hosts. More than 400 companies were represented at these 20 meetings, and the resulting interest in NASA's output in the form of new and improved manufacturing techniques, quality control, higher reliability, and new materials has been quite impressive.

Because MRI was then the only organization with an active technology utilization program, it was asked to make many presentations outside the Midwest. MRI people addressed a variety of groups—the research committee of the National Association of Manufacturers, the National Machine Tool Builders Association, the Second and Third Conferences on the Peaceful Uses of Space, and a score of professional and technical meetings throughout the United States. The concept which was discussed was a new one to most of the audiences, who were not accustomed to thinking of the Federal government as a source of much useful technical information.

The institute selected, from the MRI senior staff, a project team of competent technical people, who had also demonstrated the ability to understand and to communicate technical information in language useful to industry. This team began its work with a series of intensive briefings at the major NASA centers. The first and most pressing task was to study a vast array of NASA's findings, discoveries, experiments, inventions, and patents for case material to discuss with industry.

The technology utilization level of contents and sophistication was very different in late 1961 and early 1962 than it is today. NASA itself was feeling its way and its own in-house technology utilization effort was just being organized. The various NASA centers were not then staffed, as they are now, by competent technology utilization groups acting as intermediaries to identify and document the useful concepts from the originators, so at that time MRI had to devote a major effort to the screening and identification of industrially useful results derived from the highly mission-oriented research and development programs of NASA; nor was the climate in the country as yet receptive to the idea that the public sector possesses so vast an amount of technical knowledge useful, as well, to the private enterprise component. The major barriers of skepticism have now been breached, as a result of proven utility and greater familiarity with the actual content of space technology.

NASA now has two highly developed activities supporting the technology utilization effort. Its Scientific and Technical Information Division is documenting 33 fields of technology covering the world's output of aerospace sciences. These inputs come from the 10 NASA centers, from all NASA contractor reports, and from patent disclosures and conferences. Thousands of reports are being handled yearly. Tapes are directly searched. Two bimonthly abstract

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journals—STAR and IAA, which are broad-gage, fast-response abstract journals—range in content from the directly transferable to highly abstruse material. The NASA computer index now has random access to 130 000 different documents to which 80 000 to 100 000 are being added annually.

A complete retrospective bibliographic search of this entire collection, including computer and abstract review time, as well as reprinting from standard microfilm, is possible in 1 hour. These and other information handling techniques provide good coverage of the formal written output of NASA. This is the cornerstone of most dissemination activities of technology utilization programs.

The second group, the Technology Utilization Division, is the action transmitter of the previously discussed input and other inputs. The technology utilization people have a practical, pragmatic slant, searching for innovations, documenting them, appraising innovations for possible application (with several research institutes assisting in the screening), repackaging the data in useful form, and relaying the data to industry and business in various ways. The ability to collect and selectively package information tailored for particular interest groups is, in many cases, a door-opener for real technology transfer, by establishing a personal relationship of trust and respect which encourages discussion of deeper technical needs and problems on the part of industry.

One lesson repeatedly confirmed in our experience is that actual application of existing knowledge of new uses is accelerated when there is close personal contact between the source of the information and the user. The system requires that the dissemination service is truly selective and responsive to industries' requests for more information.

This is the difference between NASA's approach and the other efforts to transfer technology throughout the economy. It is the reasoning behind the regional dissemination experiments discussed herein. As the first of the regional experimental programs, MRI has studied and tested methods of identification and retrieval of innovations from NASA field centers; translated them into potential industrial applications; and disseminated them to industry and tested industry's response. As the pilot effort, MRI employed a broad, generalized approach which is quite different from other approaches taken.

There is a proven value in access by companies in a given region to a nongovernment center having many interests in common with the users, and particularly if that center is geared to provide fast-response, flexible, personalized reactions to industry requests. This point of view could pave the way for much closer cooperation between industry and universities, too. Just having the information available and disseminating it to industry does not insure in any way that it will be used. Far too few people are now available who are adept enough to view space technology with an appropriate industrial outlook.

The Midwestern Research Institute has been engaged in its program for almost 3 years; the first Midwestern industry meeting was held in Omaha, Nebr., on March 7, 1962. In the hundreds of personal contacts with Midwestern firms, MRI has found solid interest in virtually every field in which NASA and its contractors are working. The cases in which a company has taken bits of information and put these to use, although difficult to document completely, range from management aids, like reliability and inspection programs, through new metal forming techniques and protective coatings, to biomedical uses. Other recent examples are noted in the following discussion:

A company in Omaha, Nebr., produces electrical power conversion units, such as dc–ac–dc inverters for railroad equipment. This company reports that it was able to improve its product performance and reduce the temperature derating of its power transistors by using a heat sink material and technique developed by NASA. This company is presently looking to NASA and MRI for solid-state power inversion and conversion circuit ideas to improve on its present design.

A St. Paul, Minn., manufacturer produces transistorized digital read-out devices. In order to minimize rejects due to faulty electrical connections, this manufacturer needed to provide special training for its assembly line workers on a soldering technique. The management was able to use reference 1 as a course outline and text and reports that the detailed description of techniques shortened the training time considerably and resulted in the peak production being reached much earlier than had been expected. Similarly, a large company in Oklahoma was able to report a 40-percent reduction in failure of its electronic well-logging instruments in the field after switching to the NASA methods of making electrical connections.

A wall-board producer found that a low-cost inorganic coating developed by NASA for passive temperature control of satellites would internally protect its rotary kiln at temperatures of 800° F. The coating shows no signs of wear or blistering after 6 months of use, and the product quality has been improved because the plaster no longer is contaminated by the coating.

A large producer of ore washing equipment has experienced constant trouble with abrasive grit in the bearings used to support the huge washer arms. Air-bearings of a simplified NASA design were incorporated, and not only did smooth, nearly frictionless motion result, but the airflow made the bearings contamination resistant and self-cleaning.

Another example is the use of gas bearings in jeweler-type lathes to permit rotational and cutting speeds high enough to manufacture spindles for precision meter movements. This spin-off of Saturn guidance techniques provided a breakthrough for a small Kansas City, Mo., manufacturing firm which supplies large electronic manufactures with such meter movements.

A major producer of electron tubes visited MRI to inquire about glass-to-metal seals. As a result of personal discussions, this producer was persuaded to consider a beryllia ceramic envelope rather than aluminum oxide or quartz, and to employ electron-beam welding of the electrode structure. MRI was able to provide NASA information covering the simple control measures needed to work safely with beryllia, and to furnish up-to-date techniques for preparing ceramic-to-metal seals. Tubes having four times the power output previously possible are now made.

From information obtained from NASA through MRI, a manufacturer of engines and machines has made instruments to measure perpendicularity or squareness that greatly improve the accuracy of the machined parts.

In a similar way, a national organization with a major plant in Missouri has found that the special tools devised to aline space-vehicle parts in perfect perpendicularity cut costs in setting up precision cutting tools.

One of the specialities of a South Dakota company is the design and development of telemetry for high-altitude research balloon systems. This company recently had a great need for a compact high-input-impedance solid-state amplifier circuit for use in a telemetry system. A circuit developed by NASA was the ready-made answer to the problem and was applied without any alteration.

Sometimes the role of the applications engineer is primarily to demonstrate that technology known to the user can be practically employed and is not restricted to exotic aerospace programs.

A St. Louis, Mo., firm had been unable to produce satisfactory stainless-steel high-pressure vessels using conventional designs and fabrication methods. This firm had heard about high-energy rate forging and electron-beam welding methods, but had not considered using advanced technology which was believed to be beyond its reach. MRI project engineers were able to show how NASA had done closely similar jobs and put them in touch with service firms that performed the critical steps. The final product far surpassed the design goals—but more important, totally new production opportunities have been opened through familiarization with technology widely used by aerospace contractors.

Many NASA contributions are related to new manufacturing techniques, new materials, and new ways of doing things to improve performance and reliability and to reduce costs; there is more interest in these things than in new products, which in themselves represent additional problems, such as marketing. There is nothing automatic about the technology utilization process, although the words "fallout" and "spillover," which have been so widely used, do violence to the established fact that economic gains from technology transfer occur only when such ends are purposefully pursued. The creativity required to match an existing idea to an apparently unrelated problem, may often constitute an innovation of nearly the same order as did the creation of the original concept.

The entire conceptual problem is a major one. Only a small number of companies are accustomed to looking to outside sources of information beyond their suppliers, their customers, or their competitors. In many cases, industry, large and small, is prepared neither to receive nor to act on most new information from outside. Yet, it is almost impossible to prejudge the valid interest of a company. Space-technology transfers are more likely to occur in firms concentrating on a specific sales market, in those which have clearly defined plans for expansion, or in firms which are entering into unfamiliar technical areas. Some of the more knowledgeable companies have employed their own technical intelligence agents, but this is a rare occurrence. And, yet, the quality of information coming into a company is a major deciding factor about its future.

The stage is now set for the second-generation effort of technology utilization—an effort not directed toward more exposure of industry to space-related technology, but toward achieving greater effectiveness of use, specifically, "more utilization per unit of dissemination." Technology transfer is less a matter of spreading information than it is one of solving problems. Visits and mail dissemination are only precursors to goal-directed seeking on the part of industry. This seeking requires the development of a frame of mind in which people collaborate in seeking answers or, in some cases, seeking problems for which the answer is already available. MRI has made many changes in both approach and content. These changes can perhaps best be summed up in terms of the way the project staff has changed. The institute began with engineers and chemists and, in the second year, added an industrial sociologist with considerable experience in industrial group dynamics; last year it brought to the project the associate editor of one of the country's top industrial publications. These men, both professional communicators, work with the engineers, physical scientists, and economists as part of a well-integrated, completely multidiscipline team.

Although MRI has a longer association with the NASA program than others, it continues to seek and to find better ways to advance the use of space-generated technology—through technology surveys, special subject seminars, better repackaging of information, cooperative ventures with larger firms, and now a special program jointly with a prominent teaching and research hospital to give special attention to the medical applications of space technology.

In many areas of technology the production of knowledge has outstripped its use; this condition has resulted in a growing mismatch, which has created economic waste and some social problems, and may be due to the sheer size and rapid growth of the scientific effort. The real barriers to progress are neither technical nor financial. The barriers are outdated institutional practice, lack of entrepreneurship, and reluctance to accept new ideas and new practices.

The utility of science and the resulting technology lies in what can be done with it to expand regional economies, corporate profits, and government mission capability—local, state, or federal. The United States has generated over $75 billion of potentially useful information in the past 8 years; yet, somewhere along the line the nation is making quite inadequate use of it.

Barriers to the transfer of technology exist in four major areas: (1) within corporate management, (2) within the scientific community, (3) in institutional factors, and (4) within the human mind itself. As a prime intellectual resource, the university should be a key link in the transfer mechanism and may be said to occupy a key position at the interface between the generators of knowledge and those who should use it.

The first barrier to transfer relates to management attitudes and the absence of adequate mechanisms to deal with new products and new processes. There is an unwillingness of many managements to take risks. Managers in industry want to show a short-term profit, and many are not willing to accept new technology, to do anything which might render existing plant and organization obsolete. This is one reason why there is a much greater technology utilization interest in new processes, new materials, and new production techniques which will require only incremental change.

There is inadequate concept in business circles that government is a fruitful source of technological information. Many businessmen either do not want to use government sources, do not know that they exist, or do not know how to use them.

Another set of resistance points for technology transfer lies in the scientific community itself. One example is the Ph. D. who cannot communicate his findings or who has little, if any, economical understanding or drive. Another is the great need to distinguish between the transfer of documents—the problem to which most attention has been devoted—and the transfer of scientific and technical information, one of the key points of reference 2. Like many self-evident truths, the point seems obvious, yet it has received little attention.

There is the orientation of some scientists who regard research as a special privileged way of life, quite remote from the real world. This orientation is manifested in part by the rapidly growing preference, especially among younger scientists, to work on public problems, as opposed to seeking industrial problems and economic growth.

Scientific people have a great preoccupation with the professional journals; publication and communication are frequently confused. There is a tendency to downgrade the soft sciences and engineering. Scientists and engineers do not adequately appreciate management's skills and functions.

In the third set of obstacles there are barriers which are institutional in nature. Such barriers are an inadequate supply of real risk or venture capital and resistance to using new technology as seen in old-fashioned building codes and in automation disputes in labor negotiations.

Closely related to the inadequate use of government research and development is the lack of rapport between industry and universities; thus, a very logical source of new idea input, plus new information about technology, is shut off. There is the unwillingness sometimes seen in university people—in both the hard and soft sciences—to relate their research or academic programs to the needs of industry. And in many parts of the country, the geographic separation of industry and universities serves as an effective barrier to getting together at all.

The fourth obstacle to transfer has to do with creativity and innovation. Creativity has usually been thought of as essentially as individual endeavor, but the structure of the American society has moved in such a way that most things—both economic and social—are accomplished in groups.

Research management has generally failed to keep pace in its coupling role among research groups on the one hand and innovators on the other, and has not learned yet how to provide the climate which motivates creativity. The entrepreneurial function of management in this new climate must be discovered, that is, the ability to match the needs, wants, and goods of society with the vast ability to create and produce.

The great universities have an important role to provide training, experience, and special insights which will help to develop the skills and attitudes which make industry's managers more "innovation prone," that is, more responsive to opportunities to adapt ideas for profitable use through "out of context" matching of the essential concepts. Much research needs to be done on the effectiveness of adaptation and on the barriers limiting it.

There are both short- and long-term opportunities in this whole issue. The short term, of course, must deal with present people, present institutions, and present customs. The long term involves new people and new ways of doing things. The latter will have to be waited for, but can be prepared for now.

Hope is expressed in some quarters that the university can fulfill this transfer role, because of its wide interdisciplinary competence. The university is the major institution which can hopefully understand the significance of basic science and its potential for technology. But, universities may need to add an entire new dimension of attitude to their activities.

In the beginning, university-industry rapport probably cannot be built on an institutional basis. Development of mutual competence and respect may require man-to-man arrangements. This involvement in such problems will be painful for many, but there are already signs that it is coming at the University of Indiana and Wayne State University, for example. Results can be fruitful, but both business and universities can have a major role in developing working relationships.

One need is more professors with industrial backgrounds who can help inject in school the realities of competitive corporate life. New emphasis is needed in the college curriculum on the role scientists and engineers will play as employees in a corporation.

It is a new relationship—a new point of view—for many a university looking outward to the region it serves as well as to customary educational responsibilities.

There may be a need for the technical man who has been 10 to 15 years out of school and has some proven entrepreneurial ability to be re-educated in his field so that he has something "to entrepreneur with." The emphasis is now on producing Ph. D.'s most of whom neither possess nor are they taught entrepreneurial skills. Most scientists do nothing to broaden their spectrum but go to scientific meetings and thus compound the problem. It is significant that the Varians, Edwin Land, Richard Morse, et al., had university access continuously to go with their entrepreneurial ability. The source of much new technology was close at hand, and natural channels of communication were available.

The medical schools have done this job very well—no medical school exists without a hospital. But the sciences and technology have not done it yet. Internships particularly in engineering, where invention and technical innovation are required to such an extent, are needed.

There may be a new use for the Sabbatical Year by people who generate knowledge as a career. These people should also have to transfer knowledge as well, working at the transfer points of knowledge on occasion and not solely at the generating points.

The great challenge is how to manage the transfer of useful information generated by scientists and engineers and to relate this information to both public and private economic and social growth. This challenge will be accomplished only by a mutually purposeful, continuous effort among research scientists, business leaders, the management of universities, and government officials at all levels.

Meeting this challenge will require a reappraisal of the role of the university in society. All facets of the university—the traditional science disciplines, engineering, the social sciences, the humanities, the business school—ought to have a major role in this. These new roles are appropriate, new dimensions to meet the challenges which have their genesis in the traditional role of the university.

All who have an interest in technology utilization should make a searching and thorough study of reference 2. There is much to be gained from this terse and important work, so much so that it should be mandatory reading for all graduate students in science, engineering, and business. Reference 2 states:

> Transfer of information is an inseparable part of research and development. All those concerned with research and development—individual scientists and engineers, industrial and academic research establishments, technical societies, Government agencies—must accept responsibility for the transfer of information in the same degree and spirit that they accept responsibility for research and development itself.

Establishing a dynamic equilibrium between the production of scientific and technological knowledge and its effective and economic use constitutes one of the most critical intellectual challenges this nation faces in the second half of the Twentieth century. One of NASA's most significant contributions has been its key role in meeting this challenge by both stimulating and achieving much in the economic use of technology generated in the public sector.

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The University and Technology Utilization

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THERE is a growing interest in the process that is involved in the utilization of technology originating in basic research or advanced development. This interest is directed toward speeding up the utilization, so that the results of research more quickly affect the industrial economy. The importance of this is obvious; it greatly enhances the value of the research and advanced development to the society that is paying the bill.

It is generally recognized that universities can and do contribute substantially to the utilization of new and advanced knowledge. In support of this viewpoint, it is customary to point out the Boston area, with the Massachusetts Institute of Technology and Harvard University in the community, and the San Francisco Peninsula, with Stanford University. Such examples have led communities to feel that if they can only beef up the local college with a few extra research grants and, in addition, attract a little corporate research and development to the community, a great industrial center will soon spring up.

Even a casual testing of such a hypothesis shows that this beautifully simple formula somehow does not always seem to work. Dr. Donald Hornig, Science Advisor to President Johnson, stated in testimony in May 1964 before the Subcommittee on Science, Research, and Development, of the House Committee on Science and Aeronautics, that:

> We must experiment with ways of translating the educational capability in a region into the industrial development of that region. It is not enough to have federal funds available for industry and to have excellent universities in an area. Industrial growth does not always accompany the placing of large federal installations. Brookhaven Laboratory has not had an impact on the growth of Long Island, other than the funds placed there directly.

The Brookhaven situation is not unique. The Lawrence Radiation Laboratory of the University of California with its world leadership and large size has stimulated only a minimum amount of industry. Although the training of students at bachelor and advanced degree levels, and the performance of research by faculty and students, are necessary requirements for a university to make a significant direct contribution to technology utilization, in themselves they are not sufficient. The truth of this is shown by looking at the great variation in influence exerted by different institutions that are among the leaders in science and engineering.

It is clear that something more subtle is involved in determining whether a university is to make a major direct contribution to technology utilization. The elusive ingredients are (1) faculty people possessing the proper qualities; (2) leadership, particularly on the academic side; and (3) hard and persistent work at the job of developing interaction between the university and industry.

In some cases other factors, such as climate or central location, may help. However, the importance of these can be easily overrated; the vitality of the Boston area is certainly not due to the climate or due to Boston being located at the crossroads of a nation.

TECHNOLOGY UTILIZATION AND PEOPLE

The contribution that a university makes to technology utilization can nearly always be traced to individual faculty members. At institutions such as MIT and Stanford, there are a significant number of faculty members who make substantial contributions of this type. Although each individual person is always a special case, there is a common thread. The faculty member involved is creative and is recognized both as an authority and as an important research worker in his area of specialization. He also has broad interests that extend into the practical world, and he is thoroughly knowledgeable about many practical matters, particularly those that relate to his scientific and technical interests. Finally, this faculty member receives satisfaction when people find the results of his research useful.

Such men are to be found in both the engineering and science faculties of universities, but the frequency of incidence tends to be greater in engineering. This is why MIT contributes more to technology utilization than does Harvard, and why Brookhaven contributes so little. An important factor favoring the engineer in this connection is that the research of the engineer is more likely to be in an area where practical applications are potentially present than is the work of the "pure" scientist. However, only a fraction of the engineering faculty members at a given institution will have the combination of qualities and the versatility required to make important contributions to technology utilization.

For a university to be effective in stimulating technology utilization, a sufficient number of these "technology stimulators" must be dispersed about in the faculty to provide a certain critical mass. When this situation is achieved, technology utilization will tend to occur spontaneously. At the same time, the educational program of the institution and the way in which individual courses are taught will to a degree reflect these influences. Young faculty members with potential for contributing to the utilization of technology are stimulated by example to develop this potential as an important facet of their career. Finally, students studying in such an environment will in many cases have their personal values influenced by it, and as a result will contribute more during their lifetime to technology utilization than would otherwise be the case.

EXAMPLES

The points previously discussed will be made clearer by presenting several examples.

The first of these is drawn from an earlier era and is Vannevar Bush. When I arrived at MIT in 1922 to work for a doctor's degree in electrical engineering, Bush was a 32-year-old associate professor. He was an attractive man, who radiated challenging ideas. He was trained in both mathematics and electrical engineering, and at the time was devoting a lot of his time to developing the Heaviside calculus, now known as the Laplace transform method. This was sophisticated stuff for engineering in 1922. At the same time, Bush was well informed about many problems that were of importance in the industrial market place. For example, he was interested in the considerations that limited the practical length of 60-cycle power transmission lines; in fact, I did my doctor's thesis under him on the properties of 60-cycle power lines 500 miles long. He has also involved with computers and computing machines and helped usher in the present age of computers. Bush was also investigating gaseous discharges—today this is fashionable under the name "plasma physics"—and helped found the Raytheon Company to exploit some new ideas about cold cathode gaseous rectifiers. A few years later an involvement with servomechanisms led to the establishment of the MIT Servomechanisms Laboratory, which pioneered this field in universities and helped lay the groundwork for the present era of automation.

Bush had the research interests of a true scientist, and he was always to be found at a frontier of knowledge. At the same time, he had a familiarity with the industrial world and a sensitivity to its problems. It was Vannevar Bush who organized and led the academic scientists and engineers of the country in the research effort that contributed so much to winning World War II. During that war he was also Chairman of NACA, from which NASA was derived in 1958 by a change of name. Bush, who was an academic type, contributed a great deal to technology utilization.

My second example is from the more recent past; it is provided by the research activities carried on at Stanford on beam-type microwave tubes, specifically high-power klystron tubes and traveling wave tubes. Immediately after World War II ended, two Stanford faculty members, Edward Ginzton and the late William Hansen, became interested in developing a new kind of high-energy electron accelerator for atom smashing, based on radar techniques. In order to obtain the high energies desired, a really high power microwave vacuum tube was required—a tube generating more power than was obtainable from the magnetron tubes then used in radar transmitters. Ginzton with the help of an associate, Marvin Chodorow, undertook to meet this need by developing a very high power klystron tube. This effort was completely successful and made possible the linear electron accelerator program at Stanford which is now nearing its zenith in a 2-mile-long $116 million machine. Ginzton recognized from the start that since this new tube was a power amplifier instead of a self oscillator as was the magnetron, it would make possible a radar system with less ground clutter than was present in radar systems using the magnetron as the power source. The Korean incident provided the opportunity to test this conviction. Several tubes specifically designed for radar use were built by Ginzton, and the Lincoln Laboratories of MIT found that these tubes did give the superior performance that had been anticipated. Ginzton and Chodorow then taught various industrial groups, particularly companies with local plants, such as Varian Associates, Litton Industries, General Electric, and Eitel-McCullough, how to make these tubes. Today, high power klystrons that are direct descendents from these early Stanford models are to be found in the ballistic missile early warning system (BMEWS), in the distant early warning line radars, and in many other ground radars, as well as in tropospheric scatter communication systems and in UHF television transmitters. About half of all the high power klystron tubes manufactured in the world today are built within 10 miles of Stanford. This situation came about as technology fall-out from a project to build a great atom smasher, and it can be traced to a little group of faculty men with an understanding of the problems of the practical world and with a desire for technology utilization.

Research on traveling wave types of tubes began at Stanford in 1946. This was a very interesting and exciting activity, involving new developments in electron optics, the behavior of electromagnetic waves on new types of structures, studies of noise effects in electron beams, and so forth. After 5 or 6 years a small commercial demand for traveling wave tubes began to exist. Stanford was one of few universities doing significant work on traveling wave types of tubes. We had four highly competent and very versatile faculty members concerned with them, and we were training a steady stream of doctoral students who thoroughly understood the phenomena associated with these tubes. As a result a traveling-wave-tube industry began to develop near Stanford, helped by our faculty, nourished by graduates of our tube program, and aided by our research and our know-how. General Electric and Sylvania established tube laboratories in the area. Local companies, such as Huggins, Stewart Engineering, Microwave Electronics, and Watkins-Johnson, sprang up. Today over a third of the $40 million annual U.S. production of such tubes takes place in the immediate vicinity of Stanford. Obviously, this is not a coincidence; there was real technical fall-out from the Stanford activity.

In the research on tubes at Stanford, the practice always was to maintain professional standards with respect to design and construction techniques. Research tubes designed by students for their thesis projects were constructed as well as if not better than corresponding research tubes produced at the Bell Telephone Laboratories. Because of this, our graduate students learned not only how the tubes worked and how to analyze them, but, in addition, absorbed an understanding of the tube-making process. This greatly increased the technology utilization of our tube research program, and it may possibly have been the primary reason the beam tube industry built up around Stanford instead of at older tube centers.

My last example is provided by O. G. Villard, Jr., a faculty member of the Stanford Electrical Engineering Department. Since 1946 he and a group of associates have been carrying on a most interesting and productive research program that in part is concerned with phenomena in the upper atmosphere that can be studied by the use of radio waves. Villard and his associates have studied the frequency of occurrence, particle size, and velocity of meteors, and have devised a means of using meteors to determine wind velocities in the atmosphere at altitudes of about 100 kilometers. These men are authorities on auroral and subauroral effects; they initiated investigations that determined the source of backscatter of signals propagated through the ionosphere, and so on and so on. However, in addition to this scientific interest in the properties of meteors and the upper atmosphere, Villard and his colleagues have a very thorough knowledge of and an intense interest in the practical problems of radio communication. Accordingly, when their research uncovers something new, they are the first to see the practical implication. Moreover, once a practical implication is identified, they will assign a student the job of testing or exploring the matter further, or they will write a paper to present the idea to others.

There is a remarkable record of technology utilization associated with the research performed by Villard and his group. They demonstrated that the meteors that they studied were responsible for ionospheric scatter communication. This provided such communication with a theoretical base and, among other things, provided the basis of a nonjammable long-distance shortwave communication system. The investigation of the causes of backscattering of radio signals propagated through the ionosphere led to the technique of scatter sounding, whereby the operator of a radio transmitter can determine the most desirable frequency to use when communicating to any specified receiving location. Their work has also led to other practical consequences.

CONTINUING EFFORT ON THE PART OF THE UNIVERSITY

If a university is to make a major contribution to the development of an industrial community it must work at the job—both hard and persistently—over a long period of time. This is particularly important while the pattern of interaction is being established and before interaction that is taking place is large in amount and diverse in character. Only after a pattern has existed long enough to become traditional, and has come to involve many elements of contact, does the operation tend to become self-sustaining.

If a university is to become an important factor in industrial development, a significant number of faculty members must develop and maintain personal acquaintanceships with key people in local industry, and must participate in helping local industry become acquainted with the university and its resources. These faculty members must have a real and perceptive interest in the problems of industry so that some degree of involvement of this kind on their part is a pleasure and not an assigned chore. It is also necessary to educate those segments of the local industry that are oriented toward an advancing technology, to the fact that the university can be of great value to them, and that it is to their advantage to make an effort to learn what the resources of the university are and how they can be used.

Finally, the university must continually strive to find ways whereby it can make extra and special contributions to the local industry. It is not easy to find ways for special cooperation that do not compromise the integrity of the school as an educational institution or the creativity of its faculty members, but it can be done. There is, however, no standard pattern, and each institution works things out in its own way.

In this exercise, leadership and initiative on the part of the educational institution is absolutely essential. Otherwise, nothing very significant or permanent is going to happen. The importance of university initiative action is illustrated in the development of science-oriented industry on the San Francisco Peninsula. This development has been a postwar phenomenon that has taken place in parallel with the growth in research that has taken place at Stanford in engineering and applied physics. Before and during World War II the total employment in such industries in the region around Stanford University was negligible. However, at the very beginning of the postwar era—an era characterized by government-supported research in universities and emphasis on graduate training in engineering—there were a number of us who realized a new age had arrived, and we began immediately to see what could be made of it. In my first annual report as dean of engineering, which was released in the summer of 1947, I said, "If the West is to achieve industrial leadership, industry and the universities must recognize that they owe each other a mutual responsibility." Stanford was then already at work helping the local area develop an indigenous industry that could stand on its own feet and would have its own intellectual resources. This effort received the full and understanding cooperation of superb local leadership on the industrial side. However, in spite of the favorable initial conditions, which included incidentally wonderful climate, it took nearly 10 years of persistent effort to create the situation that now exists.

EDUCATION AND TECHNOLOGY UTILIZATION

It is my belief that the contribution to technology utilization that will be made during the lifetime of those who are now doing graduate work in engineering can be significantly enhanced by suitable educational procedures during graduate study. I have already made reference to the value of maintaining true professional standards in the design and fabrication activities engaged in by students and faculty in research activities. In addition, there are patterns of education which, while providing the engineer with the strong background and orientation toward science which is so necessary in dealing with a rapidly advancing technology, also develop in the engineer an interest in and understanding of the values of the market place.

One of the most serious problems in engineering education today arises from the fact that as students become increasingly sophisticated in the use of mathematics and of analytical techniques, there is a tendency on their part, and also on the part of the faculty as well, to

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overly analyze problems rather than to synthesize solutions. Moreover, these problems are ordinarily invented on the campus, and as a consequence are artificial in character, too often with clean-cut answers that can be found by using the textbook of the course as the guide. In order to provide an antidote for this and to achieve something of a balance in the training available to the engineers at Stanford, the university is undertaking several interesting departures in engineering education. These are all designed to bring real-life engineering problems into the classroom in an educational context.

One of these experimental programs provides Ph. D. training in systems engineering and involves a cooperative arrangement between the university and an industrial concern or a Government agency. The program requires 4 years beyond the M.S. degree and involves three intern periods of 6 to 12 months each in industry, alternating with periods on the campus. The thesis topic is generally drawn from the intern experience. This is a unique program, not duplicated anywhere else, and is attracting a great deal of attention both on the part of students and of the participating organizations.

The second new educational program consists of a design project involving team activity of an interdisciplinary character. Last year a group of 26 first- and second-year graduate students were organized into a number of working groups. These students carried out the preliminary design of a satellite system for collecting weather information. They named it SWAMI for Stanford Worldwide Acquisition of Meteorological Information. The "final examination" for this two-quarter course consisted of a 2-hour presentation of the recommended system to a panel consisting of representatives from space industry firms, NASA, the U. S. Weather Bureau, and the faculty. The results were highly praised by NASA and the Weather Bureau, and we understand that NASA is considering the release of a request to industry soliciting proposals for an early phase study of the system proposed by the Stanford class.

This year 61 students have signed up for the program; the topic for the year is a Mars exploration vehicle. Seven faculty members from six departments will contribute to the instruction. Special inputs are provided by about 20 experts from industry and from government organizations, who lecture to the group; included among these this spring will be Wernher von Braun.

The third significant educational experiment Stanford is undertaking in engineering education is a development of the case study method as applied to engineering. This program was started by the late John Arnold, Professor of Engineering Design, and is being carried on by his successors. Its objective is to bring real-life engineering problems into the university in a way that will prepare young engineers for the world they will enter after leaving college.

CONCLUSIONS

In conclusion, the main points discussed herein may be summarized as follows:

(1) A university with a good graduate program, good faculty, and research funds is potentially capable of stimulating technology utilization, but stimulation to a high degree does not occur automatically.

(2) When special stimulation does occur, it appears generally to be associated with individuals who are characterized by having good scientific qualifications including research ability, but who are also interested in what is taking place in the industrial world and the problems that exist there. Such individuals are found more frequently among faculty members in a school of engineering and in applied science departments than in pure science.

(3) If a university is to be a major influence in technology utilization in an industrial community, it must work at the job both hard and continuously over a long period of time. In general, the stimulating effect of the university is not self-sustaining until habits of interaction are well established and many participants are involved. This takes time, meaning many years.

(4) There are educational techniques appropriate at graduate level that will undoubtedly enhance the contribution that an individual makes to technology utilization during his lifetime. These techniques involve bringing the graduate student in contact with real-life problems in settings that have educational value.

(5) Technology utilization, like so many other finer things of life, does not come easily. While dollars are necessary, they in themselves will not buy the desired results; what is required is human ingenuity and human effort continuously and skillfully exerted over a long period of time.

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Programs of the Indiana University Aerospace Research Applications Center

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PROGRESS IN THE SPACE PROGRAMS has been encouraging both in terms of space research, development, and exploration and in terms of the technological transfers that have been made to civilian-oriented industries.

The question often is raised: How can the knowledge developed as a result of attempts to explore space be applied to industries serving consumer and business markets? At first there would appear to be little, if any, relationship. Supporting human life in the hostile environment of outer space, however, may involve almost every aspect of human knowledge from the physical and biological sciences to the behavioral sciences. Much has been learned about the management of complex enterprises from the complicated managerial problems presented by various of the space exploration efforts.

The lawmakers who set up the National Aeronautics and Space Administration through the act of 1958 recognized the potential that might exist in space exploration for civilian-oriented industry and made it a requirement that the knowledge gained would be made available to nonspace industries, as well as to NASA contractors. (Much the same type of requirement is set up for the programs of the Atomic Energy Commission.)

The action of these lawmakers with respect to the space program was not a unique development. The United States has been concerned with scientific progress and its potential for economic growth throughout its history. The record of the Constitutional Convention indicates that many early leaders including Washington, Madison, Franklin, and Jefferson held strong views about the importance of science, not only because of its intellectual challenges, but also as a means for advancing commerce through what was termed the "useful arts."

Richard L. Lesher of the National Aeronautics and Space Administration has selected several dates that have special significance for the early history of science, technology, and economic growth. These include the following: 1790, first patent law (also the first census); 1800, founding of Library of Congress; 1802, establishment of Army Corps of Engineers; 1803, Lewis and Clark expedition; 1807, Coastal Survey Act; 1829, death of James Smithson whose will provided for the establishment of the Smithsonian Institution "for the increase and diffusion of knowledge among men;" 1842, act in support of Morse's telegraph, establishment of U.S. Botanic Garden, establishment of Naval Observatory, and Fremont's expedition to the Rockies. Lesher emphasizes also the establishment of the Department of Agriculture in 1862 and the provision for dissemination of agricultural technology in 1882.

With the type of background suggested by these developments, it is small wonder that today much time and effort is being devoted to the exploration of space in contrast to the Rockies and that there is concern with the dissemination of space science and technology to at least as great an extent as with the dissemination of agricultural technology.

PROGRAMS OF THE AEROSPACE RESEARCH APPLICATIONS CENTER

Indiana University has been engaged in an experiment in the dissemination and use of space science and technology since 1962, having entered into a contract with the National Aeronautics and Space Administration in the fall of that year. As a result of this contract, the university set up the Aerospace Research Applications Center (ARAC) and has been undertaking to make maximum use of the results of the various research and development efforts carried on by NASA through transfers to private business firms. The programs of the center have been supported by the Indiana University Foundation, the university, and 43 business firms. Originally, 29 business firms were involved. Of these, 3 discontinued their participation for a variety of reasons, and additional firms have joined to bring the number to 43. The university had the benefit of guidance from an advisory board including representatives of a number of Midwest universities as well as business executives and government officials.

In addition to working with the materials developed by NASA, during the past year the Atomic Energy Commission materials have been utilized; and through arrangements with the Department of

Commerce, it has been possible to gain access to a substantial portion of the unclassified Defense Department materials.

One aspect of the center's programs relates to the work of the Technology Utilization Division of the National Aeronautics and Space Administration. Ideas which are believed to have industrial applicability and which have been generated by NASA personnel or the personnel of contracting companies are passed on to the member companies in the center.

Another part of the program involves making available to the member companies the various articles, papers, and scientific and technical reports which are available through NASA's Scientific and Technical Information Facility. Approximately 100 000 documents are involved, and additions are currently being made at the rate of about 1000 a week. These materials are available to the center in the form of microfiche and are carefully indexed and abstracted. The indexes are placed on a computer to facilitate rapid search. Thus, retrospective searches of the materials can be conducted on questions of importance to member companies. In addition, through the development of a selective dissemination service, each company can establish interest centers, profiles of which are placed on a computer, and as a result of this, these interest centers can be brought up-to-date every 2 weeks when new computer tapes become available, containing the most recently generated information.

Either with respect to the retrospective searches or the selective dissemination service, however, the important factor is not the computer as such or the form in which the materials are available, but rather the efforts of the staff personnel of the center who by working carefully with member-company representatives fit the materials to the high-priority interests of the company. In many cases it is not the materials, but the ideas generated by these materials, that meet the needs of the member companies.

A third aspect of the center's effort involves reaching back to NASA personnel for clarification of available information or to check out knowledge that has not yet become available in published form. This service can be used only to a limited extent and for highly critical problems, but has been used to great advantage under appropriate circumstances.

A fourth aspect of the center's programs makes provision for utilizing the scientific and management faculty personnel of the university. Panels can be assembled upon the request of any member company to deal with a problem which requires exceptional effort, where the pooling of ideas and viewpoints from several fields may, through "brainstorming" and related discussions, yield results. In some instances, the center helps to arrange for university scientists to be retained to provide special consultation services for the company involved.

In addition, the center has undertaken to provide managerial services of special types, notably in the area of long-range managerial planning and in research and development management and technology utilization. Top management developments in the aerospace industry are made available to the aerospace sectors of the economy. Additionally, some efforts are being made to also provide market and other economic projections which may aid the processes of long-range managerial planning and technology utilization. These latter services are only beginning to be developed but hold real promise, notably in the area of technical marketing services. The center is putting special effort into the area of technical marketing services at this time.

Although many of the member companies prefer not to identify specific benefits that have been received except in general terms, there is some fairly specific evidence that the work of the center has proved to be useful. In a number of instances it is understandable that secrecy would be maintained in regard to potential developments. In a general way, a number of companies have been helped to improve their internal organization for utilizing technical materials as well as to improve their communications systems.

In a number of cases, the center has made it easy for research and development (R. & D.) personnel to receive the available government R. & D. literature and often has saved them substantial time and effort. In some cases the center has been able to help companies avoid expensive R. & D. ventures because it has been able to bring them information of on-going activities which previously was not available to them. In a number of cases the center has been able to bring company people into contact with NASA personnel in areas of development where reports have not as yet been published. In addition to these types of benefits, the center has, of course, made it easy for member-company representatives to meet numerous officials of NASA, the Department of Defense, the Atomic Energy Commission, the Department of Commerce, and other government agencies in connection with the semiannual meetings held on the campus. At these meetings there has been a substantial exchange of information between the representatives of the different companies as well as between company people, university faculty members, and Government officials.

There have been some very specific evidences of assistance. One company was able to find an improved method for joining thin metal by use of the tungsten inert gas welding process. This company has invested some thousands of dollars in welding machines using this process and reports a significant saving in man-hour time on the assembly line, in extending the usable temperature range, and in providing in-house capability to manufacture components that were previously purchased. The company considers this development to be worth many thousands of dollars.

A fairly simple but still valuable transfer was reported by one company which because of its need for testing competitive products found is necessary to remove lithography from cans. Reference 1 describes a paint remover previously unknown to this company, and it was found to be very useful for this purpose. The saving is estimated at several thousand dollars annually, and an operation which had a number of hazards was eliminated.

In another case, a company was able to reduce the turnoff time of a rectifier by means of information reported in one of the documents in the center's system (ref. 2). The estimated saving in the research time that would have been necessary to develop this is between $5000 and $10 000.

Still another company was able to locate a material capable of accommodating high-density magnetic fields for use as a core material in a pen drive mechanism. By means of a retrospective search conducted by ARAC, it was possible to identify a material that would fit the various requirements but at a substantially increased cost. Because this company was able to determine that no material at what was considered a reasonable cost existed, it proceeded with a research effort in this area and produced a model that met its requirements.

In another case, joint efforts of company and ARAC personnel combined with careful literature searches made it possible to develop a new approach to a problem in the area of microencapsulation. Company officials believe that this approach was due largely to the information that was available from ARAC and doubt that it would have occurred to their own personnel.

These few reports give some concept of the potentialities that may exist. They suggest, indeed, that many companies are gaining substantial benefits from the work of the center, and undoubtedly new products and similar developments will be forthcoming and will be in a reportable condition in the not too distant future.

Thus, the work of the Aerospace Research Applications Center is contributing significantly to the programs of member companies and in turn to regional and national economic growth. It is possible that the field of research application is becoming as important for economic growth as basic research itself. If the rate at which knowledge is utilized can be speeded up, major benefits should result.

Although an encouraging start has been made in a relatively new area, much remains to be done. Experimentation in a variety of directions has been undertaken. An advisory board with members from a number of universities in the Midwestern region has been established to assist in drawing on the ideas and work of these institutions, which include Purdue University, University of Notre Dame, University of Cincinnati, University of Kentucky, University of Illinois at Chicago, Washington University at St. Louis, and University of Minnesota.

Preliminary experiments have been undertaken in providing faculty members with materials available to the center. These experiments were started on the campus last fall and recently have been extended to an experimental group at Purdue. Plans have also been developed to carry this type of activity forward at Notre Dame.

Preliminary experiments in the general areas of innovation and entrepreneurship have also been undertaken. The semiannual meeting scheduled for April 8 and 9 has been developed in cooperation with the Indiana Executive Program. The general theme of the sessions is "Innovation: Organization Climate." Several faculty members in the Business School and in the behavioral sciences have been interested in this general area, and it seems that an organizational climate favorable to innovation and to people with entrepreneurial minds undoubtedly provides a favorable environment for technology transfers and for the generation of ideas based on new information and new concepts such as are provided through the NASA–ARAC services. Thus, if improved methods for developing a climate favorable to innovation can be identified, it should be possible to further the work of ARAC.

Some experiments are also going on in the area of technical marketing services. Preliminary efforts involving the abstracting of significant books, articles, and reports in this field and the dissemination of these abstracts to member companies with provision for providing hard copy when requested have already demonstrated their usefulness.

Preliminary analyses have been made of the possibilities of using various census materials, particularly those that have been placed on a computer, as the utilization of other sources of governmental information that may be available in computer form is being investigated.

As has been suggested, top management developments in the aerospace industry hold much promise. Case studies of companies in the aerospace industry may provide valuable research as well as teaching materials.

Consideration is being given to the development of financial information that may be of special interest to member companies, but this project is still at an early stage of development. It should be noted, however, that because of previous work by several faculty members of the Business School in closely related types of efforts, it would appear likely that some definite contributions can be made in this area.

Several members of the Department of Business Economics and Public Policy have developed a series of economic projections over a number of years. This work continues and the results are being made available to the cooperating members of the center.

Various efforts in the area of long-range managerial planning are adapted to the work of the center as specific studies become available.

Several faculty members have been carrying forward studies in the general areas of R. & D. management, the management of technology utilization, and communications management. These efforts are still at an early stage of development, but have already produced results that are of interest to member companies.

These and related efforts are all contributing to the establishment of the Aerospace Research Applications Center as one of the main interdisciplinary programs being carried forward at Indiana University. It is undoubtedly an outstanding example of cooperation between industry, government, and the university on the various programs of the university that are being carried forward at the present time.

Even though some of its plans were viewed with misgivings by various faculty members at the time the center was established and even though some of these attitudes persist in various quarters, there is little doubt that the programs of the center have had a variety of influences on university personnel. Perhaps the most important development along these lines is the establishment of closer working relationships between university scientists and industry-based scientists than existed heretofore. In addition, somewhat closer working relationships between the scientists and the Business School have begun to develop. The center has become one of the main efforts of the university in adapting to the new patterns of relationships that appear to be developing between the university and the region it serves, particulary with respect to efforts directed toward the stimulation of economic growth and related activities. Since Indiana University does not have an Engineering School, the center has provided one of the few oportunities available on the campus for graduate engineers to take advantage of their previous training and experience.

Thus, it does not appear to be claiming too much to say that the programs of the Aerospace Research Applications Center have had an influence on the campus as well as on the relationships of the university to industry and to government, although in the latter case a broad set of working relationships had evolved prior to the establishment of the center.

Where all of this may lead is an open question. On the basis of experience to date, however, the opportunities for interesting and productive developments in a variety of directions would appear to be very bright. The university, industry, and government should all benefit as partners in a new type of enterprise designed as in the case of the Smithsonian "for the increase and diffusion of knowledge among men."

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Working at the Interface

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IN THE PROCESS OF WORKING at the interface between those who do research and those who are concerned with saleable articles or materials much is being learned about the elements that contribute to the effectiveness of this process. This process can be variously described as establishing a matching or a coupling mechanism between those who are oriented toward the development of new knowledge and those who are oriented toward application of knowledge. In many respects, it is a sophisticated problem in communication.

One aspect of this process of working at the interface does seem to be clear. It is not automatic and will occur only rarely if left to chance, as might be implied if it were characterized as spin-off or fall-out. Any unidirectional analogue is misleading. The process is more like a network system with closed loops providing for feed-back, a complex network with alternative paths, and characteristic input-output relationships.

Some of the experiences that Wayne State University has had over the past year from working at this interface between the research laboratory and the producing industries in southeastern Michigan are discussed herein. The university is much indebted to Dr. Charles Kimball and his associates at the Midwest Research Institute in Kansas City, who plunged early into this uncharted sea, developing a broad program using NASA-generated or related technological information in an activity encompassing several Midwestern states and involving a wide spectrum of potential industrial users. Arthur M. Weimer and his colleagues at Indiana University in similar fashion were most generous in sharing with us their experiences in developing under

NASA sponsorship a different type of program with a selected industrial clientele for promoting application of aerospace research

This paper is concerned with what is referred to as technology utilization, not because it is something new, but because many new and highly significant elements inject a note of urgency today. The useful application of discoveries or of new knowledge, for example, dates back to the time when man took the basic concept of the wheel and then fabricated two wheels, attaching them to a platform in order to make a cart which was useful to him. Now, however, the sheer magnitude of new scientific and technological information being developed in each year, from a current annual expenditure in excess of $21 billion, much of which is from public funds, makes it critically important that man develop a better understanding of the processes by which knowledge is adapted for use. Industries are establishing bridging mechanisms within companies to help in promoting effective communications between the laboratories and the production departments. General concern within the Federal Government has led to the recent establishment in the Bureau of Standards of a new Institute for Applied Technology. Its purpose is to stimulate the application of science and technology to national needs.

Of special significance, however, is the early initiative taken by the National Aeronautics and Space Administration in making possible some important pilot programs in various settings.

ESTABLISHMENT OF CAST

The meaning or significance of the particular experiment at Wayne State University can perhaps best be evaluated in the light of the rationale used for justifying and initiating the program. The university is trying to find a means whereby an academic institution can appropriately contribute to an understanding of the process of transfer, a means whereby it can develop pilot mechanisms by way of illustration, and a means whereby it can contribute to a revitalization of academic programs of study and research, particularly in the professional fields of engineering and business administration. The experiment is conducted in the newly established Center for the Application of Sciences and Technology (CAST) at Wayne State, an institution-wide administrative unit operating out of the office of the vice president for graduate studies and research.

In this center, the direct and important external objectives of the experiment are the effective transfer of results of aerospace-related science and technology to local industry. However, the experimental character of the program must be emphasized again. An effort is being made to keep the procedures and practices flexible.

The decision to undertake the experiment was not arrived at lightly. Change comes slowly, and sometimes painfully, in the academic setting. Professors, as John Gardner has put it, like to innovate—away from home. Nonetheless, changes can and do occur. Three centuries ago most of the creative scientific work, except in medicine, was achieved outside of universities. In the intervening years, however, universities have become the centers for such creative scholarship in science and have, in fact, become pace setters. They have mastered the art and science of creating new knowledge through research. They have so effectively demonstrated its value to government and to industry that all now contribute to the present fantastic and exponential rate of increase in knowledge. So successful have all been in mastering this art and science of creating knowledge that it is estimated that in the 7 years from 1960 to 1967 as much new information will be created as was produced in all preceding history. Previously, a doubling occurred in the decade between 1950 and 1960. Before that, 50 years, from 1900 to 1950, was required for a doubling.

Universities have thus helped develop techniques and methodology of research and have by teaching extended this understanding of the processes by which we learn more about the world in which we live. Can they now, in the face of the overwhelming flood of information, help us develop an understanding of the processes by which we might more effectively utilize for human welfare the abundance of knowledge at our disposal? In essence, this is the question we asked ourselves at Wayne State about 2 years ago. Can or should a university bring its talents for philosophical analysis, for experimentation, and for teaching to bear upon this problem, which may prove to be one of the most perplexing problems of the latter half of the twentieth century? It is not a trivial question. It cuts deeply into the objectives of professional degree programs, and it keeps alive the continuing debate over the relevance of applied research to an academic program. It relates to our need to apply more effectively knowledge in building cities and communities and in solving problems of urbanization, for example.

Another very practical reason for asking the question at this time at Wayne State was the fact that the university is located in the heart of a well-developed industrial area, solidly based in part on heavy industry related to ground transport. But the area was showing anxieties over not having participated in a significant fashion in post-World War II science-based industrial growth. The shortage was in application, not in production of manpower (scientists and engineers) or in research. Michigan ranks seventh in college enrollment and fourth in national production of Ph. D.'s. About one-half of the state's population is in the five counties in southeastern Michigan.

The University of Michigan is one of the nation's leaders in research, near the top if not at the top in terms of research for NASA and for DOD. Wayne State, from a late start, was rapidly building its research program, reaching a total approximating $10 million last year.

The question to be asked, therefore, was not how the center could rapidly expand the production of knowledge through research, but rather how a university could contribute to an understanding of the processes by which that which is known could usefully be adapted and employed by industry in the region.

The first step was to bring together members of the faculty from the Department of Engineering, Business Administration, the Basic Sciences, Economics, Political Science, and History. This group developed an inventory of the research capabilities of the university. The group also analyzed the research strength of the Detroit metropolitan area and identified the mix of industrial interests and productivity. Most fundamentally, the group asked how the university might engage in an experiment related to the use of knowledge. The faculty had to agree that such was appropriate or could be made so.

The product of this period of intensive discussion and analysis was a far-reaching and challenging proposal. A professor of history, Lee Benson, articulated the consensus in a proposal that a Center for the Advanced Study of the Rational Use of Science and Technology be established. He and others expressed deep personal and professional interest in engaging in such studies which would have meaning not only for industrial development, but meaning as well for more effective use for the common good of knowledge in the social sciences as they might relate to the building of better communities and public agencies. In fact, the proposal articulated a concern over the use of knowledge in many forms to help plan better, cope more effectively with problems as they arise, and, frankly, do a better job in educating students for living and working in an age of rapid and pervasive change.

Empasis was placed on the complementarity of two goals: one related to the highly rational production of knowledge through research, which has been astonishingly successful over the past three centuries; and the other one related to the highly rational use of the products of research. They should not be considered competitive, but as parts of a complete whole.

Faced with this challenge from the faculty, we undertook to develop as a first step a program that seemed manageable, feasible, realizable, and in simple fact, supportable with funds. The result was CAST, the Center for Application of Sciences and Technology. Because we had ascertained that local industry would be interested in such a program, we limited our experiment to science and technology utilization, or transfer, in local industry. Because the National Aeronautics and Space Administration was desirous of conducting pilot studies on transfer of aerospace-related technology and would help fund such efforts, we limited our information sources at the outset to aerospace-related technology and to the NASA information bank in its many forms. At about the time this decision was made, the State of Michigan, at the urging of Governor Romney, established a research fund in the executive offices through the Michigan Department for Economic Expansion. We successfully applied for a grant from such funds. Consequently, with major initial support from NASA, with contributions from local industry, and with a grant from the State, we began operation of CAST about February 1, 1964.

Although the past year has been largely one of getting the laboratory established and organized, we have held fast to two general operating principles:

(1) The operation by policy and through practice must be locked into the academic mission of the university, which is one of education in the broad sense. CAST must not become an unrelated appendage, having no tie except through fiscal or management relations.

(2) For the operation to have meaning as an experiment in technology transfer to industry, as one example of the useful application of knowledge, it must try to succeed at the process of working at the interface; it should remain flexible, try new mechanisms, and discover the elements that are essential to transfer.

While adhering to these operating principles, we are initiating plans for evaluation, for critical review of the processes, for identification of elements discovered as important, and for generalizations that might be drawn which would have relevance not only to similar attempts elsewhere but to the processes by which effective handling and use of knowledge might be utilized in other fields for other purposes.

ORGANIZATION OF CAST

The director of CAST, Mr. Bruce Pinc, reports to the vice president for graduate studies and research at present to facilitate university-wide contacts. Policies relating to the academic phases of the program and to the involvement of faculty and graduate students are formulated by a University Advisory Committee, chaired by Dean Johnson of the College of Engineering. Members of the committee include deans of the College of Liberal Arts, the College of Pharmacy, and the School of Business Administration.

Science departments and engineering departments are also represented. Because the operation relates closely to the program to be

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developed by the dean of a newly created Division of Urban Extension, he also serves on the University Advisory Committee. Quite candidly, some thorny problems arise because the CAST operation does break with tradition, and it is imperative that there be not only a forum for discussion, but as well a policy-recommending body of men holding key posts of academic and administrative responsibility within the university.

To involve leaders of the industrial community in the planning of operations and in reviewing accomplishments, an Industrial Advisory Board was created, with Walker L. Cisler, chairman of the Board of Detroit Edison, serving as chairman. Others include presidents, engineering or research vice presidents, or comparable responsible officers in industries of the region. Each industry contributing financially to CAST in its first year of operation is represented on the board. All four major automobile manufacturers, the three public utilities, banks, and a wide range of other industries such as chemicals, electronics, steel and metal-working firms, a bakery, a brewery, and manufacturers of machine tools, electromechanical instruments, and wearing apparel are represented. The board meets quarterly and advises on such matters as financing and public information procedures for interaction with industry, and on general objectives.

Structurally, CAST has two divisions: Information Services and Applications Services. Both are headed by competent professionals. The head of the Information Services Division, Robert Booth, is chairman of the Department of Library Science in the College of Education. He brings to his part-time responsibility with CAST a wealth of experience in library techniques and in new storage-retrieval systems. He is assisted by Mr. Song, who has degrees in philosophy and science and is working on a doctorate in library science. Other hard-working and by now experienced staff complete the unit that receives, processes, reorganizes, stores, and develops retrieval programs for a wide array of information. Parallel to the Information Services Division, and reporting to the director, is the Applications Services Division. It is headed by Earl Borseth, who has degrees in engineering and business administration and, in addition, has many years of practical experience with industry in product development. He is nearing completion of his work for a Ph. D. in business administration.

Because of the experimental character of the program, these two divisions were considered to be complementary to one another, neither being staff to the other. We need to develop better processes for handling information as well as insight into the procedures for transmitting it with understanding to the ultimate consumer.

The work of the Applications Services Division is carried out by Applications Engineers, most of whom are members of the faculty.

Some are established members of the faculty and a few have recently been added, having joined the staff of CAST with regular or adjunct faculty status established in an appropriate department. Last summer, 9 out of 11 Applications Engineers were members of the faculty. The Applications Engineers provide the important communications link with each industry. They engage in a continuing dialogue with their counterparts in a company, attempting to identify areas of interest, defining specific problems needing solution, or considering technological developments for the future. We are not concerned simply with the transfer of documents, the movement of papers, for that will not in any way guarantee transfer and utilization of ideas or information. Nor is it possible to define clearly the role of the Applications Engineers, for they have almost as many patterns of operation as there are companies working as clients with CAST. In essence, they explore with a client company various techniques for communication and for involvement, most often built around development of interest patterns or about identifiable problems. Fundamental to successful communication is an open or receptive attitude on the part of individuals. In fact, sometimes a matching of personalities can prove to be as important an element as matching knowledge to interest.

To complete the roster of staff or of resource persons, we have a number of graduate students in the university who work part-time as interns. In effect, they are Assistant Applications Engineers, working closely with the regular Applications Engineers. One in particular is a graduate student in history, having an interest in the history of technology as a subject for his doctoral thesis.

The Computing and Data Processing Center of the university is invaluable. Its director, Walter Hoffman, works closely with the staff of CAST in developing programs and procedures for efficient use of the facilities of the center, for using the NASA tapes, and for developing routines that can make possible reaction to inquiries for information stored in the center. I do not want to leave the impression that we are preoccupied with machine processes, with the use of mechanical systems for information handling, when other less glamorous methods will suffice or even be better. For example, last summer we employed a group of high school girls to do a thorough job of cutting and pasting on cards all abstracts from the NASA Scientific and Technical Aerospace Reports and the International Aerospace Abstracts. These are now filed and are readily available for reproduction by Xerox when requested.

OPERATION OF CAST

Ideally, CAST operates as a system comprising men, machines, and information designed to match definable user need or interest with appropriate information. The total system operates with certain functions describable as subsystems, and with typical input-output feedback characteristics of systems. As such, in operation CAST should respond to forces acting on it from without and from within. The system has not always worked as planned; we have had to de-bug it. Nevertheless, with a variety of combinations of procedures, with multiple steps possible depending upon individual circumstances, and with freedom to depart from a preconceived pattern for a given company, we have developed Applications Engineers with skill who in turn have developed techniques for effective interaction with industrial personnel, and have made the system work in what appears was a larger number of cases than we might have expected within a year of operation.

By the end of a year, we have developed work with over 100 industrial clients, some very large and some very small. The matching of information to need is important, but so also is the matching of the Applications Engineer to the problem area, or even in some instances to the corporate client. This is one of the lessons learned.

In principle, once a company expresses an interest or a desire to become active in the program with CAST, the Applications Engineer selected to have the greatest likelihood of compatability with the client because of technical background and experience arranges to visit the company and to meet ultimately with the appropriate engineer or technical person for determining the problem areas or the short- and the long-range technical interests of the company. In large measure this will reflect the internal technical capability of the company. The large companies are inclined to be more specific regarding the help they want on information and less specific regarding definition of interests and problems. The small companies are anxious to have any type of help that can be given.

One small company has, for example, recently added a technical person to its staff for the explicit purpose of being able to communicate more readily and thus to take advantage of the wealth of information available through the CAST operation which has relevance to its product line. Another company was interested in having information that would help it plan a 10-year phasing out of its present operation and a phasing in of another compatible one, in terms of its equipment and personnel skills, for it could clearly anticipate the successful undercutting of its present business by more economical materials and processing techniques.

At any rate, the Applications Engineer returns to CAST with results of his discussions and observations and either then or after another visit develops in collaboration with the Information Services staff a series of questions to be put to the information and data bank in the computer. The Information Services then queries the computer, which in turn responds with an automatic print-out of references from its extensive store of information. These references are then converted into 200-word abstracts of documents by the Information Services and are transmitted to the Applications Engineer. He analyzes all, selects those he believes most nearly meet the client's interests, and takes them personally for a discussion with his client. In this process many different things can happen. An entirely new line of inquiry can begin, triggered by unexpected information; a clue as to other previously unasked questions can be found; or, a decision can be reached on which of the documents merit further complete study, resulting in the Applications Engineer's requesting the documents in full from the Information Services. Following transmittal of further information and discussion, repeated steps for amplification or for additional searches may be necessary—or the information so provided may lead to application, either in the form of solution of a problem in manufacturing processes, reduction of losses, improvement of the product, reduction in cost, or in rare instances, opening up consideration of a new product by direct transfer.

This rather mechanistic interpretation of what in principle may be the operation of CAST does not account for the highly individualistic nature of the work of the Applications Engineer. Perhaps the most useful thing that he will do for a given company is to demonstrate the importance of the use of information available, not only in CAST but in the company's own library. Perhaps the most effective transfer is the idea of taking time to reflect, to analyze, to seek through work of others solutions to company problems, or to be exposed to materials out of which ideas for future exploitation can be created. Also, the Applications Engineer must stop short of becoming in fact a full-fledged consultant, referring instead to private consultants or to qualified faculty members at some university with whom the company could make private consulting arrangements.

One might even go so far as to acknowledge that in many instances what we do through CAST is to use the extensive information resources of NASA as a means of establishing new company attitudes, of building internal communication linkages, and of opening up opportunities to inject new ideas or approaches for corporate planning or problem solving. It is the total system approach which is important, not the fact that any of the elements or concepts are essentially novel.

When successful, for whatever reason, the approach does in fact move aerospace-related information in an applicable form into a company with a relatively high probability of its being used.

RESULTS

In the preceding sections a description of the rationale and structure of CAST and of the principles of operation has been given. How has it worked? What can be pointed to as evidences of success or evidences of difficulty? To what degree has impact been felt on the academic program of the university? What does industry think of it? Do we have any better insight into the processes of transfer, of application, or of technology utilization?

This year this organization has restricted itself to information related to space science and technology and to sources available through NASA. These materials, or information inputs to the system, comprise the following:

(1) Hard copy or microfiche reproductions of documents not found in the open literature such as journals or books. These come from Documentation Incorporated in Maryland, which provides the service on contract with NASA.

(2) Open literature, the journal articles and books, as identified by the American Institute of Aeronautics and Astronautics in New York City, N.Y. The complete articles as published are usually available through local libraries.

(3) The Scientific and Technical Aerospace Reports (STAR), prepared by Documentation Incorporated, to index twice monthly 34 basic subject categories of information. In the year 1964 it listed 25 000 discrete items.

(4) The International Aerospace Abstracts (IAA), published monthly by the American Institute of Aeronautics and Astronautics, to cover 34 basic categories. In 1964, 30 000 items were listed.

(5) Magnetic tapes, introduced by NASA in 1962, for the IBM 1401 electronic data processing system, which stores in retrievable fashion references to all items published in STAR and in IAA.

It should be emphasized that such information is reported to corporate clients in the form of simple citations or references, of abstracts if expanded description is needed, or of copies of the complete document or article when clear relevance to interest is established. The libraries at Wayne State and the Detroit Public Library, as well as others, are invaluable and essential to successful operation of the system.

Statistically, results to date are as follows:

(a) 2094 searches conducted over the year
(b) 121 000 abstracts analyzed
(c) 3112 complete documents reproduced
(d) 737 articles obtained from IAA
(e) 9 Applications Engineers employed
(f) 9 graduate student interns or Assistant Applications Engineers involved
(g) 15 100 engineering hours of work for corporate clients
(h) Over 100 separate companies participated as clients

One could add to this list of activities the many seminars, lectures, and reports given by CAST personnel at various meetings and the initiation of collaboration among universities in Michigan as they work with industries, with the CAST system offered as an information resource.

Statistics, however, are not reliable indicators of progress, of successes, or of difficulties to be overcome. For example, one of CAST's more than 100 corporate clients employs only a few dozen persons. Another is a very large corporation with 11 operating divisions working in various ways with CAST, each division being as large or larger than most of the other clients. Similarly, a count of searches made, abstracts reported, or documents delivered does not denote utilization in fact. Techniques for obtaining quantitative measures of transfer of technology and of adaptation and application of concepts or scientific information are still being developed.

In general, we have confirmed what others also have found by experience. There seem to be three broad categories of use:

(1) Direct transfer of a product or of a new process in its entirety can occur, but only rarely. We have had only one such case which we would define as direct transfer. There are many good ideas floating around, even exceptionally ingenious devices which do an outstanding job for a particular mission in space, for example. This does not guarantee that there would be a sufficiently large consumer market for commercial exploitation. Market analysis is a prerequisite for any new product development and production and profitable sale in the open market.

(2) Modification for improvement of an existing product or process for which the company already has a market is the most probable type of utilization. Need to meet competition, to solve identifiable problems, or to improve the profit position provides motivation.

(3) Under certain circumstances, particularly for the small and medium-sized companies, the work of CAST with its store of

information as interpreted and transmitted by Applications Engineers is of significant value in corporate planning and in arriving at decisions regarding research efforts.

The following examples will serve to illustrate these general types of utilization:

(1) A case of direct transfer occurred within the past few weeks. A paint used at Cape Kennedy for the gantry systems proved to be of interest to a client paint company. After much discussion, testing, reformulation and market analysis, a product was produced, and the first can was displayed at the first annual meeting of CAST of January 21, 1965. It is reported that the company had secured a sizable order in advance of production.

(2) A prominent bakery serving the Detroit area had a problem with the growth of bacteria in one of its baked products, pumpkin pies to be specific. A CAST Applications Engineer obtained the necessary NASA literature and, with the aid of two faculty consultants, succeeded in helping the client solve the problem.

(3) Amazement was expressed by the staff of a sophisticated electronics research laboratory by disclosure through CAST of important documents in their own area of specialization of which they had been unaware. Out of 50 abstracts uncovered, they had need for 14 documents. Here, the assistance was primarily in identifying interest profiles and in locating relevant information.

(4) Increased production rates and savings in tooling costs resulted for a producer of bearings through work with a CAST Applications Engineer using NASA-related information in reducing bacterial contamination of lubricating and cutting fluids.

(5) A large utility company performing research on power conversion techniques had been plagued with a problem of metal porosity. Aerospace-related information supplied through CAST contributed significantly to solution of the problem. Economic value of this one solution may be measured in millions of dollars at some future date according to one top corporate official.

(6) A large company was in the process of developing a miniature sensing and recording device, which showed promise in the prototype stage. Problems of marketing, of sales potential, and of competition were being studied. CAST, through its Applications Engineer and the Information Bank yielded 60 related abstracts. These and discussions between the Appli-

cations Engineer and the client personnel led to revision of plans, improvements, and a superior basis of knowledge upon which to make a corporate decision involving commitments of substantial sums of money.

(7) A small processing company had planned to determine effects of very low temperatures upon the crystalline structure of an exotic metal. CAST was able to report on similar tests from its aerospace data bank, saving duplication of effort and corporate expense.

(8) A large and well-established company had many rejects of its metal product because of faulty welding. Pin holes were responsible. A thorough search by CAST staff identified the NASA Lewis Research Center as having advanced information on ultrasonic leak detection techniques, and subsequently put the firm in touch with commercial organizations which produced such equipment. Preliminary results are promising and may lead to installation of a much improved quality control system.

(9) A small local firm had trouble with deep-drawing of light metal stampings. Waste and loss of profits resulted from buckling and tearing. The CAST Applications Engineer with reference to several documents uncovered in the data bank identified one report showing a solution by another company to a similar problem. The result was immediate modification by the client of his process, producing an immediate reduction of losses and an improvement in economic prospects for the company.

(10) Modification of a research plan by a large automobile company resulted from reference through CAST to work on fatigue of astronauts for Project Mercury. Information from the NASA Manned Spacecraft Center Technology Utilization Officer helped speed up the company's research program.

(11) NASA-developed techniques may, through the work of CAST and its Applications Engineer, help solve the problem of a local brewery in connection with sterilization of its bottles and equipment. The only remaining question to be answered is whether the plan is economically feasible.

(12) A large company specializing in control systems for the automotive industry wanted information on inconel. Thirty abstracts were located through CAST, of which 15 print-outs of aerospace literature were delivered and discussed with the company. The company reports they were very helpful in identifying proper uses of the metal, which is now used more

extensively by the company with consequent product improvement.

These illustrations are but a few of the many and varied types of known cases of help actually provided. In many cases, we will never know the degree to which information transfer started a chain of events leading to incorporation of partial information or combinations of information into a new product, to an improved process, or to significant modifications of development plans worth much money to the company concerned. We are discussing now with representatives on the Industrial Advisory Board procedures which might help in ascertaining quantitatively the extent of such useful transfers. Repeated use by a client of CAST is one measure. Payment of industrial contributions is another. A company's willingness to pay for time used on a fee basis in the future will be another. Actually, the dollar value of valuable technical corporate staff time devoted to consultation with the Applications Engineers also represents a corporate conviction of the value of such interaction with CAST.

In order to provide a variety of experiences, we have, as indicated previously, welcomed industrial clients of all sizes and all types of businesses. Included are all four of the automotive corporations and a variety of their suppliers of parts, materials, dies, and controls. Tool companies, metal fabricators, a brewery, a glove manufacturer, a bakery, and manufacturers of chemicals and pharmaceuticals, calculting machines, electronics equipment, tires, paper products, plastics, and optical equipment are further examples. Banks and utilities are contributors and are also beginning to find ways of usefully employing the Applications Engineers and aerospace information.

For all companies, regardless of size or type of business, a desire to participate in an open-minded approach to the process is important. Essential also is adequate internal technical competence, without which there can be no effective two-way communication or capacity for the company to capitalize on the information identified as applicable to its needs.

While we have been establishing various relationships with industry and have made great progress with techniques of handling information, we have deliberately attended to the job of relating CAST to the academic responsibilities of the university. It was previously emphasized in this paper that this is one of the two principles which must undergird the CAST operation to justify its location within the university setting.

More time will be needed for a fair appraisal, but many of us feel encouraged by the following indications that it is working—that there is beneficial feedback into the academic life of the institution:

(1) A department chairman told me this past week that to him the most exciting development was the new Industrial Engineering graduate course on "Technology Utilization." It carries Industrial Engineering Course Number IE0790. Sixteen M.S. and Ph. D. candidates, most of whom are employed in industry, are showing such interest that a decision has been made to repeat the course each term. The objective is to describe mechanisms for and impediments to technology utilization, and specifically, to utilize the CAST system in the process. It enables students to solve real problems in a professional or practical setting. The course is also being televised and recorded on video tape with the assistance of Wayne State's Mass Communications Center. Requests have already come in from other universities for the tapes.

(2) CAST personnel also teach a course in the Applied Management and Technology Center, identified as AMTC–M. 111; it carries the title, "Utilizing Research and Development Information for New Product and Process Development." This course is directed toward top and middle corporate management staff and shows how information, as stored in the CAST system, for example, can be of significant value to management in corporate planning.

(3) A still further direct instructional activity stimulated in part by CAST is a series of special courses and workshops on polymers, emphasizing the uses of new chemical technology in construction and in transportation. More than 300 participants are expected to register in this program, which is cosponsored by CAST with the university's Institute for Applied Chemistry and Physics.

(4) In less formalized but, nonetheless, effective ways, the faculty who work part time as Applications Engineers are feeding their experiences back into the classroom. One professor in engineering uses in a graduate course a special reference or source book of recent laboratory results compiled by print-out from the aerospace data bank.

(5) Another professor is using CAST and its Information Services as a means of searching for promising graduate thesis topics which would have relevance to major problem areas of interest. In fact, one department chairman has stated that he fully intends to revise his whole approach to advanced degree research through effective use of the CAST mechanism

to help insure that engineering graduate students work on problems similar to those they will encounter in practice as engineers.

(6) Promising research problems, for example, one related to microwave curing of plastics, grew indirectly out of CAST activity by two professors, one from the Department of Chemical Engineering and the other from the Department of Electrical Engineering.

(7) Two of the part-time graduate students in engineering, working as Assistant Applications Engineers, are receiving credit for directed research under supervision of their major advisors.

(8) A Ph. D. candidate in history, interested in the history of technology, is also serving as an intern in CAST and is collecting material through direct observation which will relate to his thesis topic.

(9) Professors in political science and in history have also become involved in planning evaluative procedures which will be implemented over the next several months.

(10) As a result of faculty suggestions, CAST is exploring ways in which it could be of assistance to them, to departmental chairmen, and to the Office for Research Administration in searching out literature relevant to major research proposals prepared for submission to potential sponsors.

Encouraging as this may seem, there is still not enough interaction within the university. It is largely a people problem, to quote a department chairman. He wants many more faculty members to become involved in different ways. He and his dean and a fellow department chairman all seem to agree that their greatest complaint about CAST is that members of their faculty are so interested that they spend perhaps more of their time than they should in working at the interface as Applications Engineers. In a very real sense this is an acknowledgement of the value of this experience to the faculty and, in turn, through them to their teaching and research.

In fact, a department chairman said recently that some professors are inclined to come and teach their courses and gradually die. He felt that CAST in part could serve as a mechanism to help keep them alert and alive, giving them a continually broadening experience.

This has been a good year of trial and experimentation with this new mechanism. We have been gratified with progress, but are by no means satisfied. We need to improve communications internally and externally. We have learned to be less optimistic about direct and easily identifiable results, but have to begin to sense that perhaps technology utilization will best be promoted through steady progress and development of the other less tangible but essential elements in the process itself.

WHAT OF THE FUTURE?

We remain firm in our conviction of the need to lock the operation close in to the educational program of the university, benefiting the institution in its central job of training people, while benefiting NASA in its mission of speeding application of aerospace technology in non-space endeavors. We are beginning to examine and experiment with programs of application in other sectors, in addition to industry. Governmental agencies, the nonprofit health-related agencies, even education itself can in some measure use to advantage such technologies.

As we move in this period of transition in the life of our nation, we must find new ways of approaching the problems of conservation of resources, air and water pollution, transportation, and communication. We must also find ways of effectively applying the fruits of our space researches and technology in the solution of these and other major problems, solutions of which hold such vast potential for benefit to us.

Some Aspects of the Industrial Applications Program of the University of Maryland

Philip Wright

DIRECTOR, INDUSTRIAL APPLICATIONS

UNIVERSITY OF MARYLAND

A BRIEF ACCOUNT OF THE PRESUPPOSITIONS underlying the work of the Office of Industrial Applications of the University of Maryland is given herein. The terms of reference of the work call for a study of conditions underlying the transfer of technical knowledge to the industry. In this study, use is being made of some of the NASA-generated research and development (R. & D.) which is assumed to have industrial and commercial potential. The study seeks to identify factors which may impede or facilitate the transfer of technology to industry and also considers the possibility of designing a program to advance the Industrial Applications Program of the NASA Goddard Space Flight Center and to augment its capacity to promote industrial progress in the State of Maryland. Implicit in all this, of course, is a basic assumption that positive attempts would be made to transfer individual pieces of technology. Also implicit, particularly from the university's viewpoint, is the fact that any study conducted would contribute to knowledge of the process of technology transfer.

The first considerations of technology transfer and its commercial utilization greatly affected the nature of the project. In the first place, it seemed redundant to try to duplicate techniques of technical information dissemination already being investigated elsewhere. Further, it seemed that the ultimate justification for NASA's Technology Utilization Program was the extent to which the technology was used, a use which could be measured in an economic sense. It also seemed that no particular rationale existed on which to base a claim that the transfer to private industry for commercial purposes of new technology generated by government-sponsored R. & D. had been shown effective. That there is commercial merit as an end point to an enterprise of this kind has never been substantiated in any quantitative sense. In general, all arguments in support of this enterprise are based on a belief that since so much money is being spent by the government on R. & D., there must, on first impression, be commercial benefits besides those for which the work was done in the first place.

From an examination of any of the available results of efforts to transfer new technology into the commercial sector, it seemed to be generally true that the success of these efforts constituted exceptions to a rule rather than the rule itself. For example, the total utilization of all patents issued is probably not much higher than 50 percent even when the definition of utilization is set at a very low threshold of activity. The utilization of patents in any commercially significant sense is probably not much higher than 10 to 15 percent. Therefore, in attempting to commercialize the bits of any particular corpus of new technology, irrespective of the patent situation, it seemed unreasonable to expect success in more than about 10 percent of the cases. This means that from a commercial viewpoint, up to 90 percent of available new technology at any given time is unlikely to find immediate commercial application. It seemed, therefore, that an immense amount of time could be wasted in attempting to process new technology in detail and in trying to uncover nonexistent commercial applications for it. That fact remains, however, that there is a high probability that for any 100 items of new technology, perhaps up to 10 of these might find significant commercial application. It is also conceivable that one of these items might have transcendental application commercially. The problem is to identify them, since they can be of national importance in terms of the gross national product.

It seemed that some relatively quantitative guide might be developed to divide new technology into that portion which may tend to become profitable commercially and that portion which will tend to remain just interesting laboratory exercises. If this could be done, it might be possible to optimize, but not maximize (there is still a law of diminishing returns), the transfer of this new NASA technology to the point of utilization and, among other things, to advance the Industrial Applications Program of the Goddard Space Flight Center.

This view, of course, is somewhat at variance with that of documentalists who tend to regard any one document as being as significant as any other document just because it is a document. Absolutely, this may be the case. In the context of industrial utilization it cannot be.

The University of Maryland project is a relatively modest one in financial terms. This fact reinforced the thought that over a wide spectrum of technical subject matter, market and investment variables, and industrial manufacturing and marketing techniques, it is ill-advised for one man or even a small group of men, however skilled and experienced, to consider that they can provide all the answers to all the questions which so divide new technology. The chance that any particular bit of new technology can meet the extremely specific and extremely diverse requirements of one industry, or a company in an industry, or a division of a company in an industry, or an individual in a division of a company in an industry seemed quite remote and extremely difficult to assess a priori. These observations led to a consideration of the sources and kinds of evaluation. A panel of scientific experts divorced from the imperatives of the profit motive can pronounce on the technical feasibility of any new proposal. Pronouncements of this kind do sometimes suffer from a kind of ambivalence characterized by statements of the general form "on the one hand this, but on the other hand that." Alternatively, there can be, for almost any reason, an establishment-like conspiracy either to support or frustrate any proposal for the further development of the idea. In any case, the merit of the scientific panel consideration frequently resides merely in the fact that the panel has examined the new proposal. The failure of any further action or the failure to take any further action can ultimately be justified by this fact, and in any case it is always safer in this context to say "No" than to say "Yes."

It will perhaps be generally agreed that to assess technical viability is a more defined and therefore simpler task than to evaluate commercial potentiality. In the context of NASA R. & D., technical merit can almost be assumed. The work has been performed by qualified people in response to some well defined need. In the end, the Office of Industrial Applications decided to forego the benefit of such technical advice and guidance.

A gap in the otherwise impeccable conclusions of many scientific panels is in the areas of marketability and profitability. Traversing the question of whether formal market research can effectively be done in the context of new products and processes, attempts to remedy this lack expeditiously seemed to suggest contact with industrialists and individual companies. The purpose of this contact would be to obtain an evaluation of the commercial significance of a particular new development in terms of the reaction of its potential destination in industry. If this evaluation were in positive terms, a ready-made user would already be available. This does seem, on reflection, rather like asking a buyer to explain to you the merit of what you are trying to sell him and does not, on the fact of it, seem to accord with the best principles of free enterprise. However, this merchandise is very special merchandise.

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Only after the item had not been rejected outright as a viable proposition could it be said that any progress had been made; that is, a condition of nonnegativeness would be reached. At this point, it would be fair to say that transfer had been accomplished with some kind of prognosis for utilization which would vary from a little over zero upwards. In parenthesis, it should also be noted that transfer is accomplished even when a condition of negativeness is reached, since, in theory, as detailed an evaluation is called for to say "No" as to say "Maybe" or "Yes." Much evidence of transfer is of this kind and contains a wealth of detailed reason.

Finally, the views of industry about the commercial significance of selected items of NASA technology were sought, and industry was invited to use them. For any total population of items, the output-input ratio for this process in terms of a nonnegative outcome seemed unlikely to be greater than 0.10. In terms of any total number of industrial approaches, the ratio would probably be about 0.01. The psychological impact of so much abortive reviewing would be cumulatively disenchanting to the businessman and could reduce the effectiveness of the evaluation process. Hope of new products and therefore new profits exists always. However, this could not be relied upon exclusively to give an adequate motivation in this context. Something needed to be done to utilize this motivation more effectively.

Contacting industry on an irrelevant, unnecessary, and incompetent basis has been avoided. If this is not done, industry will react superficially or with complete indifference. Moralizing about the businessman's duty to himself, his stockholders, his staff, and the community at large will effect little in the context of the businessman's ever-present preoccupation with his current production and marketing problems. It may not be necessary actually to present to the businessman proof of an immediate net profit of 30 percent per annum achievable at substantially no investment within the first 6 months of operation. However, as other programs have concluded, something more sophisticated is required than exposing the businessman to an uncritical selection of technical reports and challenging him to justify the basic tenets of free enterprise by taking up the commercialization of their contents at his own risk.

It seemed clear that too much emphasis could not be placed on a properly directed but ruthless neglect of technical literature of no evident intrinsic interest to industry. This, it was hoped, would create and maintain an encouraging psychological response from industry itself by not submerging it with digests of technically meritorious but commercially useless material. Some discriminating selection and communication technique was therefore imperative. The information transferred had to be palatable to and assimilable by the industrial recipient at his level. Otherwise it was not likely to receive proper consideration. Furthermore, in all fairness to the industrialist, since there is likely to be 90-percent wastage, this information had to be of a nature and in a condition that would enable him to come to a firm and definite conclusion based on his knowledge, judgment, and experience in a minimum of time. If the component of "can't say" or "can't say without other reference" in his evaluation is at all excessive, then the resistance to doing anything rises markedly.

In other words, in order to avoid failure, the right material must go to the proper companies in the appropriate condition. There is a variety of subject matter, of presentation modes, of presentation conditions, and of presentees. The variation here is large. In addition, new technology can be characterized on bases other than that of subject matter, for example, function. Companies are characterized by features other than their product range, for example, geographical location. The University of Maryland program is attempting to compare and contrast some of these various things.

Some of the practical aspects of the Industrial Applications Program, which, it is hoped, will be accomplished are the following:

(1) To catalyze and facilitate the commercial utilization of a proportion of the NASA technology and to sustain situations of nonnegativeness to the point of commercial utilization, while making observations about the nature and characteristics of such a situation.

(2) To measure the relative effectiveness of various modes of approach to industry.

(3) To indicate particular areas of technology, in a subject matter sense, where the prognosis for utilization is higher than for others.

(4) To identify, in general terms, industries and companies in which the prognosis for utilization is more pronounced than in others.

(5) To show the effect of dissemination in a restricted geographical area on the amount of technology transfer achieved.

(6) To compile industrial views about the merit of the whole Technology Utilization Program, the general nature of the barriers to utilization, and the specific reasons why, in any particular case, a particular piece of technology does or does not have commercial appeal.

There is a strong desire on the part of the members of the group to attempt to approach some quantification of all these things, even if it is not entirely possible to do it. You might describe the current feelings of the group as a combination of a suspicion that we may be mistaken with a conviction that we are right.

During 1964 (the program has been in existence a year) the group postulated about 7500 combinations of companies with innovations and took the initiative in this. Some kind of emotional involvement was needed to transfer the enthusiasm that the innovator presumably has for his innovation over to the destination.

Nevertheless, the group postulated approximately 7500 combinations of companies with innovations and tested the hypotheses; 4300 involved Maryland companies and 3200 involved companies outside Maryland. Since these hypotheses were based on subject matter, it was difficult to remain within the boundaries of the state.

Having reached a point after all this, where we can, in the context of our terms of reference and as a practical matter, no longer positively urge most of these situations further on to the finality of commercial utilization, we are left with about 300 situations of nonnegativeness, 4 percent of the postulated figure, each with a varying prognosis for ultimate utilization. Of this total, about 100 are in Maryland, slightly over 2 percent, and the remainder, about 6 percent, are elsewhere.

Comments—Session V

***Dayton**, Montana State College:* Has there been much, or any, complaint from independent consultants and consulting firms concerning these activities?

Kimball: I would say quite the reverse. I think in our efforts we have unearthed a considerable amount of work for consultants. In fact, in one year as a result of this and other activities of ours we made some 400 referrals of work to testing laboratories and small consultants.

Whaley: I would like to add to this because I made reference to the fact that in a sense one might interpret our work as a very extensive consulting job. We have not encountered this problem. Commercial practicing professional consultants have wanted to work with us; our work is really an augmentation and, in fact, stimulates work for them.

***McMillan**, University of Omaha:* Dr. Whaley, you mentioned that one of your objectives was to put your operation on a business basis. How do you handle your charges for this?

Whaley: The first year we operated with very generous support from NASA, support from the state of Michigan, and contributions from industry. The industrial members of the Advisory Board had a committee working on a fee basis for the future. Now, we do not think fees alone will do the job. We want to incorporate a continuation of the contribution approach because some industries, banks, for example, are not going to use us directly, but they are making contributions, and we hope they will continue. So it is a combination.

Weimer: I should have mentioned this in my paper. I said we started out asking $5000 from large companies and $500 from small ones. It soon became clear that this wasn't fair or adequate, so we made some readjustments. Roughly, for $750 we provide broader services for a company, but they are not put on the computer. For $1500 they get the broad services plus one interest center, and then it goes up by steps with three centers at $2500.

Simpson: Generally speaking, the NASA policy falls somewhere between encouragement and requirement of a self-supporting situation. At Indiana somewhere on the order of $2000 or $2500 is charged for a basic service. That is in the realm of reason for most companies, even small companies, for the basic computer service.

***Curry,** University of Maine:* Dr. Wright, would you comment further on the selection processes by which technology possibly of commercial value is identified.

Wright: The selection process was based on the diverse experience the three members of our selection panel had in industry and in research and development. If none of us thought an idea had possibilities, it was out; if one of us thought it good and the other two did not, the one was given the option. If we all approved, we were knocking on doors the next day.

Weimer: We might note that the technology utilization reports are screened originally by a group of research institutes and they cull out on the basis of their industrial experience a good many items before they come to us; then we, in turn, abstract the reports and send them out. So there is a gradual narrowing down process.

***Stevens,** Brown University:* Has conflict of interest been a problem?

Weimer: To date I don't think it has been a problem because all our companies have equal access to all information. We honor their confidence and their requirements for secrecy where necessary. We don't try to let one know what another one is interested in, we just give them all equal access to the same information. It takes some while to get the confidence of the companies and to have them assured that we will maintain their confidence as required, but we have not found this to be a difficult thing to do.

Simpson: I think this marks perhaps the principal difference between this as an industrial extension and the old agricultural extension idea. NASA is a little bold in taking this pilot project approach, whereas agencies not mission oriented might not be able to approach it. We are going to go as far as we can on an experimental basis.

***Pike,** University of South Carolina:* Dr. Whaley, what kind of industrial experience have your applications engineers had?

Whaley: In nearly every case they have had relatively extensive industrial experience, but it is not necessarily of recent time. In essence, they are retraining themselves in this operation. The graduate students clearly are training because this is their first exposure. Members of their faculty who have sometimes reluctantly taken on this work have frequently become so excited by it and so stimulated by it that they are spending more time on it than their chairman would like, so they are now trying to get a greater number involved and spreading the work around a bit.

Pike: Were your people screened for this purpose or did you just happen to find them on the campus? In other words, did you attempt to find people with the backgrounds you wished?

Whaley: Faculty deans and department chairmen were all exposed to the concepts. It was discussed at great length. They were asked to be the transmitting agents back into their departments to involve their faculties, so that we observed all the channels of communication from the outset. There was nothing compulsory about this work; it was purely voluntary. There are some people who want to do it and who have the background and the interest and the motivation.

Kimball: In selecting the people to work on the Midwest Research team we tried to obtain people who were as widely informed as possible. You can't just select people from classical disciplines like electrical engineering, chemical engineering, or physics. We tried to recruit people with a sort of universal mind combined with a competence to put ideas across. There are only a few people on our 350-man staff who have both qualifications.

Session VI—Research Facilities

***Chairman:* Donald C. Holmes**
Chief, Research Facilities Division, NASA

***Coordinator:* Richard M. Ulf**
Office of Grants and Research Contracts, NASA

Educational and Industrial Impact of the NASA Materials Research Center at Rensselaer

Richard G. Folsom

PRESIDENT, RENSSELAER POLYTECHNIC INSTITUTE

THIS DISCUSSION WILL COVER in a broad perspective the Materials Research Center at Rensselaer shown in figure 1. This building was constructed under the first facilities grant made by NASA on September 25, 1962. The grant was for $1.5 million for 56 000 square feet (gross). An additional grant of $0.5 million was made by the National Science Foundation (NSF) for an Engineering Science Wing that cost $1.1 million yielding a total cost of $2.6 million. As shown in the photograph for identification, the NASA Materials Center is lighted; the NSF wing is not. The building has 96 000 square feet and cost $27 a square foot including laboratory furniture. This figure compares quite favorably with an average cost of $35 per square foot for the first 15 facilities grants made by NASA.

Figure 1.—The Materials Research Center and the Engineering Science Research Wing.

This facility is closely related to the NASA supported materials research program. This program was given a large impetus in September of 1960 with an initial NASA grant of $300 000. As a matter of record, Rensselaer was chosen after visits by a NASA technical committee to five well-known Eastern colleges and universities. The funding was done in a stepwise fashion with $100 000 being allocated for the first year 1960–1961, an additional $100 000 for 1961–1962, and the remaining $100 000 for 1962–1963. Since 1961, an additional $300 000 has been allocated annually, and this figure is the current level of NASA support. This step funding is advantageous because it allows for planning over a 3-year period.

The materials program has been interdisciplinary from the beginning. Essentially, the idea has been to bring together a variety of disciplines so that each can learn from the others. Basic and applied research is beginning to erase the artificial barriers that separate such fields as chemistry, physics, and mathematics and such disciplines as aeronautical, chemical, electrical, and mechanical engineering. In the Materials Research Center, scientists and engineers of many disciplines work side by side in research areas of common interest. The desirability of training graduate students in the broader areas needed for understanding the complex problems facing the development of new materials has long been recognized. At Rensselaer an effort is being made to give this interdisciplinary idea a firm basis. The experience with having several disciplines under one roof has been one devoid of major conflicts, although one professor defined interdisciplinary research as being research carried out by *his* students on another professor's equipment.

In 1960, to handle the NASA program, Rensselaer remodeled a former dormitory and converted it to laboratory space. This building although suitable as a temporary expedient was soon filled to capacity by the addition of new faculty and the rapid growth of graduate enrollment. First-year graduate students can be taken care of by classroom space, but, when they start research, suitable laboratory space must be provided. A proposal for the Materials Research Center was submitted to NASA in June 1962 and the grant was made in September 1962. On November 30, 1962, a proposal was submitted to NSF for a matching grant to build the Engineering Science Wing. Both agencies were given copies of the two proposals. Since the NASA grant had already been approved, it was realized by NSF that, if the total construction could be carried out simultaneously, at least $100 000 could be saved. (The NSF wing was an alternate with the base bid being for the NASA building. Other alternates were included. The contract was awarded on the total review of base bid plus alternates. The contractor selected was low bidder on both the base bid and the overall bid. There were six qualified contractors who made sealed bids). Fortunately, NSF approval came through in time to permit such an arrangement. The cooperation between NASA and NSF in regard to Rensselaer's facility is to be highly commended.

The materials program supported by NASA is directed by an Interdisciplinary Materials Research Committee consisting of eight faculty members and an administrative assistant. The eight faculty members include three from materials engineering, one from chemical engineering, one from physics, and three from chemistry. The materials research supported is basic in scope and directly related to the research interests of the professors involved. Broadly defined, materials research could cover any research area. For the NASA program, however, research is concerned with solid materials, for example, ceramics, metals, polymers, or composites of these.

DESIGN AND CONSTRUCTION OF FACILITY

The coordination involved in the design of the facility should be of interest. The selection of the architects for both the NASA building and the Engineering Science Wing was approved by the Board of Trustees on October 12, 1962. A Building Committee was formed to work with the architects in designing the interior of the building. The Building Committee was composed of four professors, the building engineer of the Institute, the business manager, and an administrative assistant. Two of the four faculty members were assistant professors, and this is an important point. At Rensselaer the materials program has been kept dynamic by involving the young faculty as deeply as possible. Each faculty member was allowed to design his own particular laboratory within certain boundary conditions. Since the climate is reasonably temperate, air conditioning was installed only in those areas where it was needed for experimental work. The offices were placed in the front of the building, while the laboratories were placed on the sides, in the rear, and in an interior island in the center. (See fig. 2.)

A photograph of a typical laboratory is shown in figure 3. The design of each laboratory is suited to a particular objective. Some idea of the complexity involved in the mechanical services in this building can be obtained from figure 4. Although the physical design and layout of this building are important considerations, even more important is the involvement of this building in the educational program.

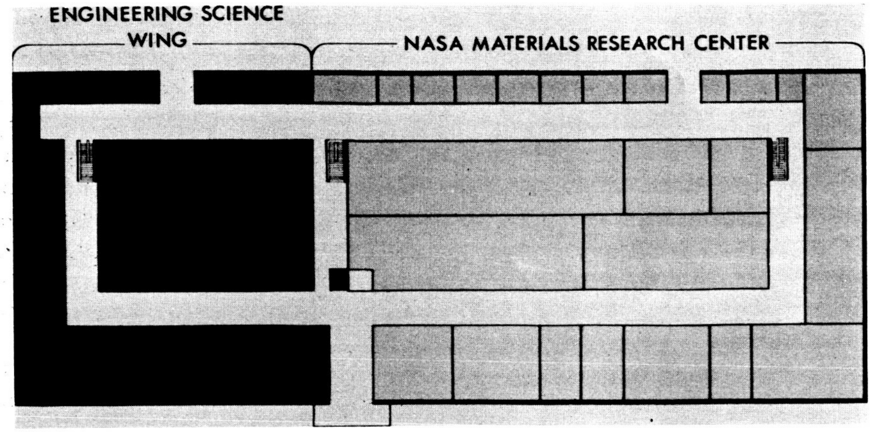

Figure 2.—A schematic diagram showing the interior design of the building.

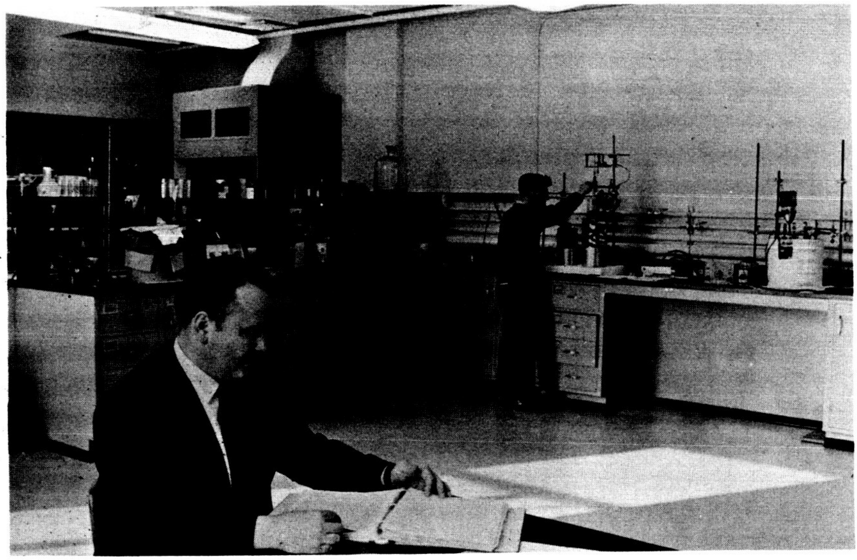

Figure 3.—A typical laboratory in the Materials Research Center.

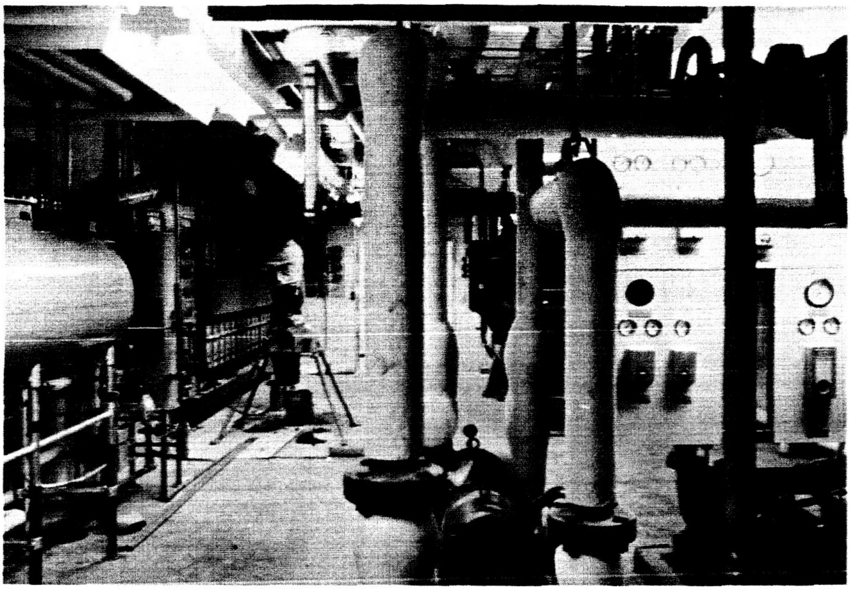

Figure 4.—One of the mechanical service areas in the Materials Research Center.

MEMORANDUM OF AGREEMENT

In connection with the facilities grant, Rensselaer signed a memorandum of agreement with NASA, which states in part Rensselaer will undertake, in an energetic and organized manner, to create a broadly based, multidisciplinary team to explore mechanisms whereby the progress within materials research in particular, and space science and technology in general, may be fed into the industries and segments of the economy with which Rensselaer normally has close relations.

The memorandum of agreement is quite general in its scope, and a good question to ask is what steps can an educational institution take to implement this agreement. During the past two years, representatives from numerous industries have visited the campus and obtained direct reports from the professors who are conducting NASA and other sponsored research activities. Mr. Webb of NASA has taken a personal interest in this connection, and from his correspondence, visits were arranged for several companies. The laboratories are open to any concern that wishes to visit and talk to the professors concerning their research work. Also, close contact with the NASA "in-house" laboratories has been maintained. A large group of the faculty involved in the Materials Research program has visited the Lewis Research Center to review research areas of mutual interest.

On October 6 and 7, 1964, a meeting was held on the campus to review the polymer program at Rensselaer and to acquaint the scientists and engineers with some of the polymer problems faced by the NASA laboratories. Ten representatives of NASA attended this meeting. As a follow up, a professor from Rensselaer visited Langley Research Center to advise them on a specific problem.

The information developed at Rensselaer is disseminated by the more conventional means of publications, reports, and magazine articles as well as through visits and talks by the staff to various industrial organizations throughout the nation. As an example, one professor recently published a fundamental article on polymers in the Scientific American. This overall program coincides with one of Rensselaer's policies, that of being of service to industry.

For the past several years, there has been a chorus of comment and interest in "spin-off," a process whereby industry benefits from Government-funded research and development. There is universal agreement on the virtue and potential of the process. Congressional architects of the Space Act established the National Aeronautics and Space Administration with a mandate to set up a program to assure the widest, practical, and appropriate dissemination of information about its activities and their results. NASA organized the Technology Utilization Division to define and implement the program.

A primary requirement of the spin-off process (also referred to as technology utilization) is efficient information processing. This difficult task of collecting, processing, and distributing the results of NASA Research and Development (R&D) has been handled on a well-conceived, effective program utilizing publications such as STAR (Scientific and Technical Aerospace Reports) and IAA (International Aerospace Abstracts) and university information retrieval centers such as ARAC (Aerospace Research Applications Center) at Indiana University, CAST (Center for Applications of Sciences and Technology) at Wayne State University, and KAS (Knowledge Availability System Center) at the University of Pittsburgh. The program has shown notable signs of progress and increasingly frequent evidence of technology utilization. Concurrently, there has been mounting impatience and dimming of expectations regarding the economic returns that can be expected from the space programs. This attitude is often the result of unawareness of the many examples of direct spin-off and the innumerable and continual indirect benefits to the commercial sector of the economy from space-generated technology. One indirect benefit results because basic research supports graduate students who increase their capabilities and, in many instances, ultimately end up in industry. In this example, industries are the direct recipient of indirect spin-off.

Rensselaer is currently seeking support to accelerate the spin-off process by adding engineering translation to complement the information-processing function. The pressing need for engineering translation becomes evident when it is realized that not only the small industrial concerns but the large concerns as well have difficulty in establishing a mechanism for benefiting from research and development. We propose to furnish industry with this engineering translation by utilizing Rensselaer faculty and a nearby engineering concern in areas of competency.

MEANING OF NASA FACILITIES GRANT TO RENSSELAER

It is not difficult to evaluate the overall effect this facility has had on the campus. The Materials Research Center has been an important factor in helping Rensselaer to attract faculty with high capabilities in particular research areas. For example, professors have been added in the ceramics research field.

With the addition of new faculty members our research has shown a steady increase since the materials program was started in 1960, as illustrated in figure 5. At the current rate, our research program will

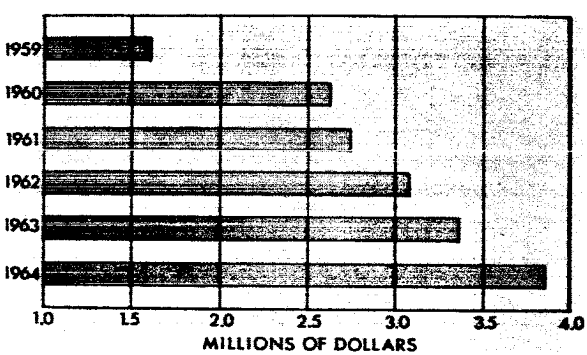

Figure 5.—Growth of research at Rensselaer during period 1959–1964.

exceed 4 million in 1965. Although the materials program is not the only factor involved in this increase in research, this program has acted as an effective catalyst for other research programs on the campus. Most important is the increase in the number of graduate students who have come to Rensselaer in the last few years. Figure 6 shows the increase in the past 5 years. Without this new facility, Rensselaer would not have adequate laboratory space to accommodate these potential scientists and engineers. Education is our primary function and in consequence our research effort is closely related to our educational program. For example, our research is of such a fundamental nature that it provides the basis for doctoral studies for our graduate students.

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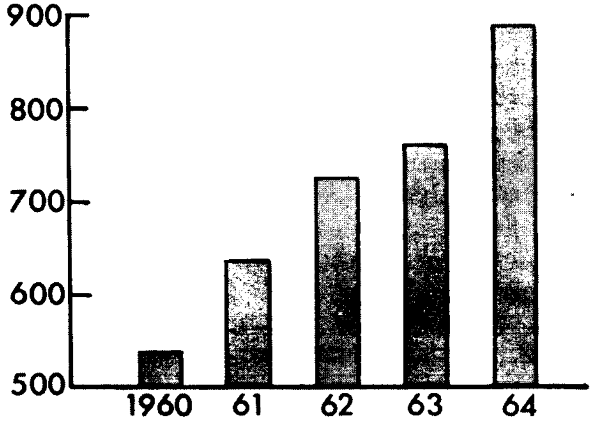

Figure 6.—Growth of full-time graduate enrollment at Rensselaer (Troy campus) during the period 1960–1964.

It is appropriate to conclude by quoting remarks made by Homer Newell before the Senate Committee on Aeronautical and Space Sciences in November 1963.

> We are relying heavily upon the leadership, integrity, and creativity of the university community. It, in turn, must accept its share of a national responsibility. We believe the results of such a partnership will be well worth the effort to the universities, the NASA, and to the Nation.

Rensselaer concurs that the results of such a partnership are indeed well worth the effort.

Space Programs and the Total University

Edward H. Litchfield

CHANCELLOR, UNIVERSITY OF PITTSBURGH

THIS PAPER CONCERNS MY PHILOSOPHY with regard to space programs and universities. Much of it will seem quite obvious, but it has taken me a while to elaborate and perhaps there are others who are still in the process of such elaboration and articulation.

Dr. Folsom has referred to the Memorandum of Understanding. There are three or four major commitments in those Memorandums of Understanding, one being that of building our capabilities on an interdisciplinary basis.

Second, we are all committed to what is popularly referred to as spin-off. This is really the process of using the university for the purpose of fostering economic and social growth. Such a purpose lies well beyond our traditional understanding of the university's responsibility in society.

There are several other points, including a commitment to help the public to understand more fully the real significance—academic, economic, and social—of the space program in general. I think the universities are committed to an effort to bring into their programs a greater degree of private support to the end that this important national effort will not be based entirely upon governmental subsidy.

My own concern in regard to the Memorandum of Understanding has been to fit it constructively into a philosophy of the role of the complex university in our society today. It seems to me that in undertaking a commitment of this kind we are talking about a new role for the large and complex university in our society. If we look at the traditional role of the university before World War II and the development of this new partnership between government and education, we find that we had the responsibility of providing teachers with an opportunity to teach, students with an opportunity to learn, and academicians with an opportunity to do research. Our end product was more people better educated, knowing and discovering more things.

As institutions we felt that our obligations were largely discharged if we appointed the teachers, erected the buildings and maintained them, provided the libraries and the laboratories and the other essentials, and, finally, if we established a tradition of free inquiry and maintained it zealously against those who might threaten it. Putting it negatively, we seldom regarded ourselves as having definable problems that we had a responsibility to solve. That view of the university as an institution had a number of consequences. The first was that we never really organized our universities. We were very loosely held together. The decision-making process, important as it is in complex institutions at any time, has never been adequately handled in universities. The respective roles of trustees, administration, faculty, and students in the decision-making process have not been articulated to the point where there would be general agreement about what they should be. We did not organize ourselves in the way that other institutions did, because we did not have the need for identifying problems, calculating alternative solutions, making the hard decisions that are always involved in policy making, and then organizing and staffing and financing in order to carry out the agreed-upon courses of action.

Again, still as a consequence, we have never developed, even today, adequate means of communication within our institutions. On few campuses do the engineers really know what is going on in medicine, and consequently we are not developing the field of bionics the way we might because the communication channels are either nonexistent or sporadic in character, or actually have downright obstacles deliberately established in order to prevent communication.

The faculty in the business school seldom knows the thinking of the law school faculty. This lack of communication can be seen throughout the university. I am not critical but am simply pointing out that the autonomy of institutional life which has developed around the traditional concept of the university is not one that leads to real organization.

Again, in the absence of a concept of the university as an instrument for achieving something other than the traditional values, we note the lack of a philosophy regarding the way in which the university should relate to government, to corporations, and to other established institutions within our society; this lack also results from our past preoccupation with strictly academic matters. I would suggest that the range of institutional interests has broadened substantially in recent years as a result of certain developments in our society. I do not mean to disparage the traditional values. I think almost everyone clearly accepts them; almost everyone is dedicated to maintaining them. I am saying only that I think we are beginning to see the emergence of something additional which we must do in defining our role.

What are some of the compelling considerations? There are two which show what I have in mind. They are simple but quite fundamental, I think. One is the growing realization that a large and complex university has a unique opportunity in society because it, better than any other institution, has the capability of integrating a broad spectrum of knowledge that ranges across virtually the whole of human experience. The point is not the mere presence and juxtaposition of these several bodies of knowledge in one place. Rather, the unique opportunity is that through this institution there is the possibility of achieving a greater integration of knowledge than can be effected by any other institution in our society. So as this role becomes more clearly recognized, it becomes more evident why university organizations are capable of accomplishing tasks no one else can. To me this is the more fundamental way of viewing interdisciplinary relationships, since it stresses the use of the total institution as a way of integrating very complex knowledges.

The second factor which I believe forces us in new directions is today's rapid growth in the accumulation of knowledge, a growth in which the large university has played, and must continue to play, a key role. It has had a key role because here is the source of much of the new knowledge. Here also is a repository for that knowledge, whether generated in the university itself or outside, and, finally, here is a vehicle for its systematic dissemination, which no other institution seems prepared to undertake.

These two considerations I think we must look at carefully for they give the university the responsibility, in my opinion, of changing its role in this society. Now let us put beside these two points something else, which is not a change in the fundamental character of the university, but a new demand upon it.

Essentially, this demand is for partnership. It may be a demand for partnership from government—from NASA, for example, or from any of the other governmental agencies. It also may be a demand for partnership with the economy. Just to oversimplify the matter, let us consider the demand for partnership with a corporation. I think there are three phases that may be involved. The first one is what is referred to as the flight from teaching—the departure of faculty members from the campus into industry, thus in effect establishing a partnership between the two institutions, though not of a planned or agreed-upon character. Indeed, the universities have not been very happy about this development. Nevertheless, it represented industry's desire to be in partnership with the academic world, even if by means of pirating people from university campuses.

We are now in a second phase of the same partnership, and this is the increasing return of those same people from industrial research to campus life. This movement I have referred to, perhaps unfairly, as the return of the native.

I think a third phase is coming, and this will be the sophisticated one. It will more closely resemble what we now enjoy in our partnership relationships with the Federal Government; it is a planned accommodation between corporate institutions and educational institutions in which the movement of people, the development of projects, the joint use of equipment, the sharing of resources generally, and the planning of professional growth are things which we shall do cooperatively in precisely the same way that we are now working with NASA.

So there have been fundamental changes in the character and direction of academic institutions, and new demands have been made upon them, including the demand of partnership. Both factors make it necessary to develop a broader concept of the role of the great university in contemporary society.

To put the matter very simply, I believe that what we need to do now is fully and frankly to acknowledge that in addition to its traditional functions, the great university has, today, the role of serving as a comprehensive vehicle for social action. This means that it must acknowledge problems (and space is one), that it must dedicate itself to doing something about those problems, that it must organize itself so that it can carry out that dedication effectively, and that it must staff itself with reference to that problem and its part in finding a solution. I think all this is relevant to our relationship as university people to the NASA program. I think that until one accepts the university role I have described, one will have difficulty in recognizing how eminently fair it is for NASA to want this kind of Memorandum of Understanding.

Until we acknowledge that space is our problem as well as NASA's, and that we are going to attempt to solve it, as NASA is, I do not see how we can make sense of our commitment to spinoff or of our commitment to develop faculties systematically in space-related fields, when it may very well be that if left to their own devices, faculty members would elect to go in quite different directions. When we undertook the commitment to broaden capabilities in space-related fields, we really said that we would deliberately engineer the direction in which our faculty development would go, whereas in a more traditional setting this would not have been an institution-wide decision, but rather something that would be left to the inclinations, the capabilities, and the philosophical bent of the faculties themselves.

These are fundamental commitments, and, in my opinion, they only become honest commitments as we recognize that they are central to a changing institutional role. Failure to recognize that really makes them figments of the association process, possibly even fraudulent in character. At the University of Pittsburgh, we accept such a redefined role for the university, and on that basis we welcome the fact that we are participating with NASA in this kind of undertaking.

It may be of interest to describe very briefly what we have done at the University of Pittsburgh to fulfill our commitment. With reference to the first of the four points, that of strengthening the space-related disciplines, we have added more than 130 people in the last few years to the various faculties in the space fields. A number of buildings are under construction. One, being built with NASA funds, is almost completed; in addition, we are in the process of building a new engineering building for which we have $14 000 000 in hand and hope to raise another $5 000 000, another natural science facility costing about $9 000 000, and making additions to the radiation laboratory in the amount of $4 000 000. All of these are funded and moving ahead.

As one of our ways of integrating a total institution, we have created what we call our Space Research Coordination Center. This is a coordinating enterprise that involves every faculty on the campus in an effort to make this a total institutional commitment. The Director reports directly to the Chancellor's office, so that if we have reluctance somewhere along the line as far as participation is concerned, we can move promptly to find out what the difficulty is and try to resolve it.

In terms of the second point, the effort to make the products of our research available to industry, we have done a number of things. We have created an organization called the Oakland Corporation, responsibility for which is shared by the University of Pittsburgh, Carnegie Institute of Technology, Mellon Institute, and several other sponsors. The purpose of the Corporation is to build an industrial research park in an area immediately adjacent to the campus and more particularly to the science and engineering facilities. We have also developed a center which we call the Knowledge Availability Systems Center. That is our way of referring to information storage, retrieval, and dissemination. This is a fairly large undertaking, for the Center is working not only in space fields but also in legal information retrieval and a variety of similar areas. We have a joint arrangement with NASA and with local industry; part of the effort is funded by industry, part of it by NASA, and part of it by the university.

Again, in an effort to share what we know with industry, we have developed a visiting program for industrial scientists, who come to the campus for extended periods of time and then return to industry.

In terms of making the public more fully aware of the total space effort, we have arranged a number of photographic exhibits. We also have programs which are intended to awaken the interest of secondary school pupils, as well as a series of other activities.

With regard to helping the general public become interested, we have had reasonable success in persuading six foundations and a number of corporations to contribute more money annually for the maintenance of this program than we receive from NASA. This support will, it is hoped, be a continuing thing.

I should like to return to the point with which I began, namely, that all these activities are of a kind which no academic person can perform honestly, in my opinion, until he has made the philosophic judgment that today's university has a new and different role to play in society. Unless this proposition is faced squarely, we are going to develop the ambivalent attitudes that many academicians have today about what we should and should not do in relation to the Federal Government, whether in research or in a variety of other matters. This is a philosophic question, and I think it needs to be answered unequivocally. I think this is a pioneering effort that will have significance far beyond what we accomplish in our space activities, since it must inevitably clarify the basic role of universities in contemporary life.

University Research in Space and the Role of Facilities Grants

J. A. Simpson

LABORATORY FOR ASTROPHYSICS AND SPACE RESEARCH
ENRICO FERMI INSTITUTE FOR NUCLEAR STUDIES
AND DEPARTMENT OF PHYSICS, UNIVERSITY OF CHICAGO

PERHAPS THE MOST SERIOUS QUESTION facing the experimental sciences today within the universities is how to retain the essentially individualistic role of faculty both as investigators and teachers in the face of the increasingly complex demands for technical support required for first-rate research. This is popularly called the problem of "big science" and is appearing in many fields of research today. Even more difficult is the participation of graduate students in on-going research so that they grow into scientists and not supertechnicians. It is our unshaken belief on the basis of the development of science and scientists over the last century that the drive and curiosity which motivates senior investigators within the university also provides the best intellectual environment for graduate students to learn and to be inspired by participation in scientific discovery. Indeed the two components—research and the metamorphosis of students into scientists—catalyze each other so the result is a higher level of excellence than is normally achieved by the pursuit of either component alone. These activities are most fruitfully conducted within the walls of the institution of higher learning where the student is obtaining his higher education.

The attainment of these objectives has become acute in such rapidly developing areas as high energy physics and, more recently, in the pursuit of experiments in space by university investigators. My attention is directed to this problem of the "big science" character of experimental space sciences, and how the recent bold step taken by NASA in offering facilities grants is crucial for the universities in the solution of these problems. My comments are not to be interpreted as a plea for turning back to the "good old days in science," but rather a plea for innovation within the universities to meet the challenge of the changing conditions of scientific research in the use of Federal funds.

To bring into focus these new "ways of life" in the conduct of experiments in space, let us compare the pursuit of high energy physics and the opportunities for space experiments. In high energy physics, experimental facilities are the federally financed accelerators located at a few centers in the United States. Once a university investigator has received a Federal grant, administration and technical interfaces with the Federal agency thereafter are minimal. His main interactions are with the users group determining the selection of experiments and use of the accelerator and with his own laboratory at the university. If his students participate they must go to the accelerator. His constraints on the design of his experiment are limited only by physics and his budget. In spite of these diverse problems, there remains, a homogeneity of interest central to the discipline of physics as understood by physicists within an individual department.

In the pursuit of experiments in space, human communication interfaces, of necessity, are totally different. Our Federal Government through NASA has provided to the scientific community an impressive array of opportunities to enter directly into the space around us for research and exploration. The machinery for accomplishing these tasks is a national resource—which, because of the magnitude of the effort—must reside in control of the Federal Agency. As a consequence, university investigators must recognize that their initial decisions to undertake experiments in space are followed by detailed, continuing collaborations and interactions between themselves and the administrative and technical staffs concerned with the overall success of the spacecraft and the mission. (Here I set aside those special cases where the university undertakes the full responsibility for a whole spacecraft and its mission.) This results in stringent boundary conditions to be met for power, weight, data handling, environmental conditions, and so forth, the responsibility for which must be accepted by the university investigators if they wish to retain the integrity and control of the objectives of their experiment. Attention to these matters cannot cease until the data from the experiments are under analysis in the laboratory. It is therefore obvious that the administrative and technical interface is totally unlike that experienced in high energy physics, constituting a multitude of parallel communication links between the university investigator and NASA staffs. All these conditions may well result in establishing a "big science" character to the pursuit of the experiments. In general, the investigator in retaining the responsibility for success of his experiment also must deal with industry from time to time. We therefore see that we are soon conducting "big" science with small instruments. Previous discussions have dealt with these problems in detail.

There exists another critical distinction between a field like high energy physics and space research which creates problems within the university. As noted previously, high energy physics is comfortably centered within a traditional department discipline. However, in one sense, space science is not science at all—yet in another, and deeper sense, it is all of science and therefore interdisciplinary in character. For example, almost any area of astrophysical investigation today involves knowledge of combinations of fields such as particle physics plus astronomy; atomic physics plus atmospheres of the planets; and so forth. So in the rapidly changing character of this research what was an interesting combination of talents yesterday transforms into a new combination today—new arenas of collaboration are constantly required within the university living space to exploit the space sciences fruitfully over many years. In space sciences the simplicity and unity of classical fields (and departmental administration of them) are broken. These differences in the pursuit and conduct of experiments in space require administrative and technical innovation on the part of the university and its senior scientific staff and students with the objective of retaining on the one hand their responsibility for the experiment and, on the other hand, the drive for scientific excellence within the laboratory.

Among the several ways in which universities may approach this problem I outline one which we are attempting at the University of Chicago. A small technical staff has been trained to assume responsibility for most day-to-day interactions with the appropriate NASA offices and their technical and administrative personnel. This usually results in a few professionally trained individuals of high caliber working closely with the scientific staff in the laboratory. Administrative support is supplied by the university administration directly in the laboratory. A manager of technical services and an administrative aide are available to assist the few faculty members involved in these activities. An assistant to the vice-president of the university carries many of the burdens that would normally be channeled through the Director of our Institute and the Office of the Dean. Although Chicago has no department of engineering or applied sciences, we note in general that talent drawn from departments such as electronics engineering is not likely to be satisfactory since the support staffs for scientific investigations are primarily of a service nature and seldom in themselves are a challenge for faculties from engineering or the applied sciences.

The general picture emerges of individual faculty members supported by small professional staffs whose purpose internally is to assist in the preparation of experiments for space and, at the interface, to maintain communication channels with NASA.

What about the goals we set for the graduate students? At the predissertation level, they assist in the theory, design, and preparation of experiments in the first stages of design, and often through to launch. They assist in the analysis of data and the preparation of computer programs for research. At the Ph. D. dissertation level, students trained in experimentation and the analysis of data are frequently made coexperimenters in experiments under way which lead to new results. At all levels of graduate participation, the students also play the role of tutors to the younger undergraduates and graduate students working within the laboratory. Normally the leadtime of a major experiment is at least 2 years from inception to execution. This fact, coupled with the possible failures inherent in space flight, means that most students will participate in the preparation of an experiment that will take place long after their thesis preparations. For their thesis work they therefore participate in an already on-going experiment having similar objectives and, from this, extract new results. It is important to note that we insist that the students publish their results alone with no coauthors. This is a fail-safe procedure for students and helps launch them on their scientific careers. We provide space for the students to work out their own ideas and to make their own mistakes!

From the topics on which I have touched it is now abundantly clear that both the universities and NASA face serious problems in the pursuit of this partnership. For the universities, it means a rethinking of their role in providing support for faculties and students with administrative revisions for technical personnel—and being responsive to faculty needs and change. On the part of NASA, there is an equally clear responsibility to recognize the essentially fragile nature of the intellectual spirit which must be maintained within research areas of the universities. The Headquarters of NASA has understood this and has done an outstanding job in providing facilities grants, traineeships, and support for research. However, the Centers and contractors operating under NASA which are assigned to work with the universities are only gradually learning that they must not treat universities as "industrial facilities" with excessive reporting, accounting, programing, and so forth. This is a particularly critical problem on planetary missions.

The main point of this discussion is that these innovations for the pursuit of scientific excellence and the training of future scientists require a unifying of disciplines and support staffs within a suitably designed physical facility—this is the reason facilities grants are of prime importance to the universities.

At Chicago our efforts to attack this problem have taken the following form. From its inception in 1945 the Enrico Fermi Institute for Nuclear Studies has been a focal point of several interdisciplinary activities drawn from physics, chemistry, and astronomy. The new laboratory built under a facilities grant, inherits this tradition and is an extension and regrouping of interests in astrophysics coupled with a suitable technical staff to prepare and carry out experiments in space. The laboratory has some additional capability to help new faculty get started in various experiments and in this sense acts as a "seedbed" for faculty entry into space sciences. For example: Using the developments and instrumentation from cosmic ray physics, it has been possible to assist A. Turkevich in chemistry with the instrumentation necessary to perform the Rutherford alpha particle experiment on the lunar surface whose purpose is to determine its chemical composition. Thus, the availability of the technical staff is the decisive factor between the conceiving of an idea and its eventual inclusion in a space mission—in this case, Surveyor. The faculty members in residence working in theory and experiment in the new laboratory are S. Chandrasekhar, E. N. Parker, P. Nordlinger, P. Meyer, and myself. Utilizing the special facilities for low-level radioactivity counting are the radiochemists A. Turkevich and E. Anders of the Fermi Institute. The new laboratory is connected by a tunnel to the existing Fermi Institute, with supporting facilities in the Computation Center.

The new building which we occupied in November 1964 is shown in figure 1. In addition to the two floors shown there are two underground levels. The gross square footage is approximately 44 000 square feet with 55 percent of this being work area. A typical cross-

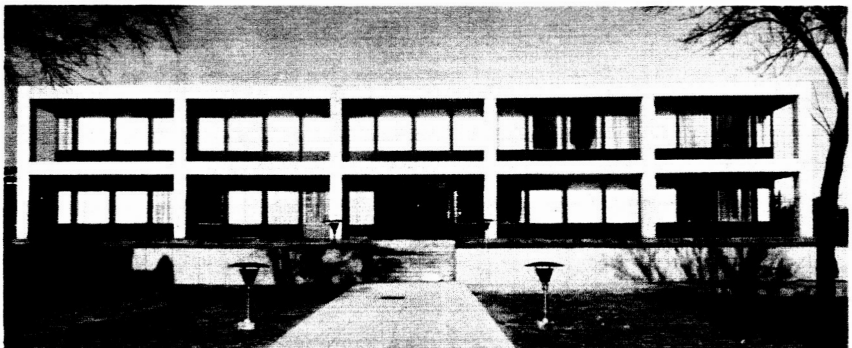

Figure 1.—Laboratory for Astrophysics and Space Research, Enrico Fermi Institute for Nuclear Studies, the University of Chicago.

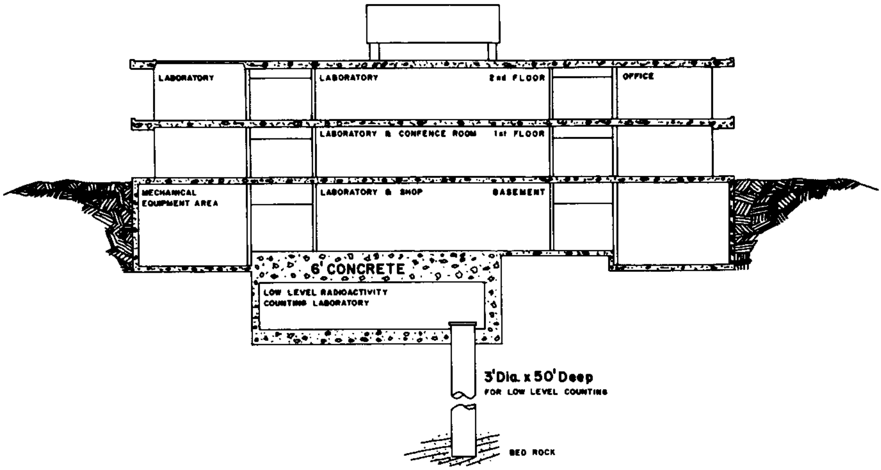

Figure 2.—Cross section of Laboratory for Astrophysics and Space Science, Enrico Fermi Institute for Nuclear Studies, the University of Chicago.

section vertical view of the building is shown in figure 2. The three upper floors contain all the necessary experimental and theoretical facilities for the laboratory and offices for faculty, students, and technical staff, as well as their laboratories. The heavily shielded underground laboratory was carefully assembled using concrete and other materials with low radioactivity. This represents a laboratory whose low background in the years ahead will be extremely useful to the faculty. Although laboratories could be built in caves or the like, which would further reduce the background, these would not generally be accessible to graduate student participation or near radiochemical facilities. This new laboratory is thought to represent a suitable compromise in this regard. The deep shaft is designed to perform special experiments at ultra low levels in the future. The laboratory is currently used for studies of meteorites and, in the future, for the study of lunar samples returned by the astronauts.

Having stated all these things, we should set a figure of merit for student participation. Taking into account the entire population of the building including laboratory boys, secretaries, and so forth, after 4 months we find that 28 percent of the building is occupied by students. One-third of these students are undertaking dissertations at present. This student population will further increase in the months ahead. Without this facility, our efforts would have remained fragmentary and our ability to sustain experiments conducted in space would be strictly limited, if not impossible.

In summary, the following special points might be considered by the universities and NASA regarding the conduct of experimentation in space.

First, there is the special character of planetary missions. Here problems of ultra high reliability and meeting the "time schedules of the planets" are important. Considerable discussion is needed as to how best to accommodate the universities in these particular missions.

Second, NASA may well wish to consider how very small university groups not prepared to establish new laboratories or centers may be helped in undertaking experimentation leading to space flight. It may be necessary to further encourage the NASA Centers, and it may be appropriate for the larger universities to encourage smaller groups to join them in preparing experiments.

Third, serious consideration should be given to the old idea of making block assignments in well-developed spacecraft for university groups so that the enormous amount of time and effort spent in exchanging technical information is brought to a minimum. It would seem appropriate that the OGO spacecraft may serve this function for the universities.

Finally, regarding the release of scientific data following a space experiment, it is essential that some patience be exercised in the public release of the data since graduate students are normally deeply engaged in this work and they proceed somewhat more slowly than a professional group working full time in this field.

So far, in the universities we have not been smart enough to solve all our problems which inhibit scientific research using Federal funds. However, with the demonstrated good will of NASA and other Federal agencies we may find the solutions which will assure the flourishing of science in the years ahead.

Panel Discussion

CHAIRMAN: **Alfred O. C. Nier**
PROFESSOR AND CHAIRMAN, DEPARTMENT OF PHYSICS
UNIVERSITY OF MINNESOTA

Gerard Kuiper
DIRECTOR, LUNAR AND PLANETARY LABORATORY
UNIVERSITY OF ARIZONA

Elliott Levinthal
PROGRAM DIRECTOR, INSTRUMENTATION RESEARCH LABORATORY
STANFORD UNIVERSITY MEDICAL SCHOOL

K. G. Picha
DIRECTOR, SCHOOL OF MECHANICAL ENGINEERING
GEORGIA INSTITUTE OF TECHNOLOGY

Chester N. Winter
PLANNING OFFICER, UNIVERSITY OF COLORADO
and

Andre G. Buck
CHIEF, RESEARCH FACILITIES AND EQUIPMENT DIVISION
AMES RESEARCH CENTER, NASA

KUIPER: I would like to underline the importance of student training in connection with space oriented programs. We have such a program at the University of Arizona.

Recently one of the small student groups made, for the first time, infrared observations of the Planet Mars, recording the entire infrared spectrum over the range at which the detector was sensitive and making comparisons with terrestrial geological samples. It is this kind of research which prepares the student for eventual participation in more difficult work in space missions.

I would further underline the great importance of ground-based astronomy. Here again university departments can make a great contribution to the national space program. The recent work done by university groups on Mars at an expense of perhaps $10 000 to $20 000, had it been done in space missions with spacecraft, the cost would presumably have exceeded a hundred million dollars.

This is not to say that the space missions are not important and should not be done. It is only to stress the obvious truth that there should be a balance between ground-based support and space missions. There are many missions, such as the Ranger missions to the moon, which could not have been done in any other way. For example, consider a Ranger mission costing on the order of $28 million. If one computed what sort of telescope would be needed on earth even to approach the resolution obtained by a Ranger, one would arrive at a figure of much greater magnitude; in fact, such a telescope is completely beyond the technical capability at present. Therefore, while we in universities usually think of the space missions being very expensive, we should not forget that our Earth-based efforts also are becoming expensive as the power of our tools increases. For instance, the x-inch telescope which is being considered by the National Science Foundation to be placed under the sponsorship of the Lick National Observatory, and which might have an aperture of the order of 300 to 400 inches, would cost approximately a hundred million dollars, and the resolving power would be only 1 percent of that of Rangers VII and VIII at the closest approach to the Moon. So I think that researchers in the universities should not be overawed by the great expense of the space missions; what they should constantly attempt to do, in my judgment, is to assist NASA in the evaluation as to what should go on those missions and what can be done by more conventional means.

One other comment might be made about the role of the university space oriented programs. They are most demanding. Certainly the Ranger program at the University of Arizona has been very demanding, involving a large number of trips to the Jet Propulsion Laboratory, and 16-hour days. This is possible only if the university administration has an understanding of the program. At the University of Arizona this was solved by the appointment of research professors.

A suggestion for university administrations to consider very seriously: Make it possible for a small number of faculty members to give complete attention to NASA programs so that these men can be freed when it is necessary from their normal academic duties.

As far as the grants are concerned, NASA administration has supported the space oriented program at the University of Arizona with a grant of $1.2 million for a space facilities building. This building has now been designed and it is expected that construction of it will begin soon. It is five stories high, has 50 000 square feet, and will house groups taken from about six departments in the University. With this new facility, I think that our participation in the NASA programs can become much more effective because we will be able to do the work more easily and do more of it.

We have also been fortunate in getting a grant from NASA for a telescope. I am proud to report that the optics for this 60-inch telescope are better, I think, than any large telescope ever made, to better than a fortieth of a wave. The image is eight one-hundredths of a second in diameter in laboratory tests, one-twelfth of a second of arc.

We have also been engaged in site test work, which again is a university–NASA relationship. By means of a small NASA grant we have been able to ascertain whether sites better than those in the Southwest would be available elsewhere in the United States, and we have made tests comparing sites in southwestern United States, Chile, and the Hawaiian Islands. Out of this has come the discovery that Molokai, which has an elevation of nearly 14 000 feet, has astronomical conditions which are, to the best of our present knowledge, better than those at any other site in the world. I would expect great results from such a site in the tropics where the planets are right overhead, so to say, where the humidity is exceedingly low year around, and where the atmospheric conditions are excellent.

I think the universities are able to assist the NASA programs in a scientific manner, which has been clearly explained by Dr. Simpson, and I think that conversely the universities are benefiting by being able to participate in this great national program.

LEVINTHAL: These remarks are especially relevant to the planetary missions and to the particular discipline that now goes under the name of exobiology. One has the difficulty in exobiology that scientific results cannot be hoped for, as such, until the 1970's, depending upon the good fortunes and exact framing of the Voyager missions. The initial actions pertinent to the Stanford facilities grant under the NASA program were taken in 1961; scientific results will be possible at the earliest at least a decade from that time.

This is a long time for people, particularly those who have academic roles and academic ambitions, to maintain a viable and important interest in a subject and at the same time carry out their academic interests and responsibilities. This requires that one find an on-going relevance of the research interests of this field to terrestrial problems in related disciplines. Fortunately, this is not only possible, but happens quite easily. It is fortunate also that NASA, in providing both facilities and program grants, has recognized the importance to their programs of allowing this kind of interest to be nurtured.

In the first place, the questions raised by exobiology have forced biologists and biochemists to frame the basic aspects of this subject in perhaps a new way. It has not yet provided any answers in the sense of scientific results that have had an impact on their sciences, but it has forced them to ask questions about the basic structure of their assumptions. It has asked interesting questions about the role of molecules containing isometric carbon centers and their uniqueness in informational micromolecules that form the basis, we think, of any reasonable definition of living systems. Some of this has come out of a NASA-supported National Academy summer study during which a group of scientists considered these problems.

Without underestimating the value of such general considerations, this cannot be sustained over a period of a decade as the core of academic interest in the field of exobiology. One finds a surprising relevance of exobiology research and research that will give results of importance long before there are actual exobiological missions. There is a relevance to the terrestrial concerns, for example, of medical science. A few examples of this, which were initiated before moving into the new NASA facilities, are occurring in the Instrumentation Research Laboratory at Stanford. (These new facilities, for reasons having to do with their inclusion within a medical school building have taken somewhat longer to complete than some of the other facilities within the NASA facilities program.)

One example is given by the possibility of detecting the functional presence of enzymes in connection with the design of simple life detection instruments. The particular assay sought is for a phosphatase enzyme. This enzyme has the property of cleaving to a phosphate bond. If, in fact, one finds a fluorescent molecule with a phosphate group attached to it that does not fluoresce, one could observe the presence of this enzyme by the fluorescent residue left after an attack on this bond by such enzymes.

This requires the development of extremely stable substrates because the figure of merit of this test is its ability to find a very small number of microorganisms and consequently very few enzyme molecules. The goals are for substrate stabilities of better than one part in 10^8. There are many enzymatic assays that are of interest to both the clinical medical profession and research in the basic medical sciences. Some of Leonard Herzenberg's work in Stanford's Genetics Department concerning antigen-antibody relationships requires exactly this kind of assay to look for the sites on cells in which various functional activity takes place. There is the same requirement for extremely stable substrates to extend the sensitivity of the assays. Under laboratory conditions, one can actually look for the activity of single enzyme molecules.

This is another interest which is now engaging a major part of the attention of the Instrumentation Research Laboratory. Payloads that might be relevant to anticipated missions are now somewhat larger than those initially considered and thus allow equipment of more complexity. This interest is concerned with the biological applications of mass spectrometry. The hope is to look at a spot of interest in the field of view of a microscope, and after volatilizing this spot, to be able to deduce from the fragmentation products revealed by mass spectral analysis the nature of the parent molecule. If one considers for a moment the information content of such a beam of ions and the problems of analysis, one sees that a solution of this problem requires a very close coupling of computer technology to the physical and engineering sciences.

Now, again, it is not a concidence, that this has relevance to terrestrial problems. Professor Shooter, also of the Stanford Genetics Department, is interested in the distribution of protein in the nervous tissues of the brain. In order to carry out his researches he ultimately needs a tool that can carry out a detailed survey of a large number of tissues of the distribution of very subtle differences in protein content. He requires exactly the kind of tool that is needed for future exobiology missions searching for signs of life in a small sample of Martian soil.

The last example also reflects a problem of research organization that is as difficult both for the academic community and for NASA as exobiology itself. Initially there was thought to be a possibility of a 1966 payload that could carry 50 to 100 pounds of instrumentation. This error in judgment as to the reality of that possibility was shared by a great number of people due to underestimating the lack of knowledge of the nature of the planets and the difficulties of achieving such missions. The investigators in the Stanford Instrumentation Research Laboratory considered the cytochemical applications of ultraviolet microspectrophotometry. It was expected to be able to get pictures of samples of Martian soil down to the limits of light microscopy. The difficulty would arise in knowing whether spots of morphological interest were in fact microorganisms or simple physical structures that had no particular biological relevance. Utilizing the characteristic nucleotide UV absorption at 2700 Å, one could scan the unknown material and observe the absorption characteristics of each spot. In order to do this it was necessary to learn how to carry out the video data analysis and to design the imaging devices required for the solution of this problem.

There was a change in the Instrumentation Research Laboratory's interests when it became apparent that the then-still-hoped-for 1966 mission had the possibility of landing only 1 to 10 pounds of instrumentation on the surface of Mars. Ultraviolet microspectrophotometry no longer seemed possible within that weight restriction, and it might have seemed at the time that the research efforts expended were somewhat wasted. It turns out that this was not the case. In the first place, such considerations are opened up again by the possibilities of Voyager missions. It also turns out that these investigations have a very real relevance to interests of people in other laboratories. In using an ultracentrifuge to effect density gradients of samples of large molecules one looks at the optical densities of bands that are formed. It is also desirable, while the rotator is moving at 50 000 rpm, to know the UV absorption of the individual bands. The equipment that is now being prepared to make these observations is exactly the equipment that was relevant to the exobiology mission.

PICHA: Multidisciplinary research, although rather slow in developing at the Georgia Institute of Technology, began to produce fruitful results and considerable interaction between faculty members about a year and a half ago. The five major space related fields of study where noteworthy interaction between engineering and science faculty members and their students has taken place are energy conversion, nuclear processes, materials and materials processing, systems engineering, and transport process. This somewhat spontaneous and informal faculty interaction in space related research activities was formalized to some extent in the spring of 1964 by the creation of a Space Sciences and Technology Board.

The faculty members involved in expanding space-related multidisciplinary research at the Institute quite correctly recognized that expansion of research activity in these areas could take place only if substantial additional research facilities were made available at an early date. Preliminary plans were developed for research space that would accommodate our expansion over the period 1964–69. Our thinking was that a structure providing 100 000 gross square feet of general purpose research laboratories as well as more special kinds of research space for hypersonic tunnels, magnetogasdynamic facilities, and so forth, would be necessary. The group charged with carrying out the preliminary planning suggested that a lecture room building with at least five large lecture rooms, each with a capacity of 125 students, also be constructed for the usual science and engineering courses at the Institute as well as lectures concerned with space-related subjects. A second purpose proposed for the lecture room building was that it might be used as a conference center when classes were not scheduled.

Planning the Space Sciences and Technology Center was of course considerably easier than finding the money to actually build the Center. A proposal was submitted to the National Aeronautics and Space Administration requesting support for 50 000 gross square feet of research laboratory and office space at a cost of $1 million. It seemed wise to separate more or less the structure proposed to NASA from the rest of the Center in order to provide a reasonably identifiable structure for NASA to support. The Institute agreed to seek funds for the second research building if NASA provided funds for the first building. The effect of the announcement of the NASA grant for $1 million to begin the construction of the Center was gratifying and at the same time a bit surprising. State funds to support partially the second research building and the lecture room building were immediately assured.

Funds for the Higher Education Facilities Act of 1963 which directs the U.S. Commissioner of Education to make grants for (a) undergraduate instruction facilities (Title I) and (b) graduate research and instruction facilities (Title II) were made available about this time. Title I funds were sought and awarded to construct the lecture room building. Nearly $280 000 of Title I funds matched by $560 000 state funds provided the total funding to construct the lecture room building.

Funds to complete the second research building have been requested under Title II of the Higher Education Facilities Act of 1963 as well as from the National Science Foundation. Perhaps it is worthwhile mentioning that the Office of Education funds are granted on a one to two matching basis while the NSF funds are granted on a one to one matching basis. Because of the difference in allowable items for funding established by the two agencies, the funds requested from the two agencies are reasonably close.

The Space Sciences and Technology Center at the Georgia Institute of Technology could be used as an example of the way several Federal Government agencies and the State of Georgia have worked together to provide major funds to establish greatly needed research and teaching facilities. To my best knowledge, the only agency empowered to provide funds to construct research and teaching facilities that was not approached was the National Institutes of Health. It should also be pointed out that if the National Science Foundation sees fit partially to support the construction of Building 2, Federal funds granted for the building of the Center will have three matching requirements. NASA provided all the money to complete the first building; the second building would require roughly a one to one matching, whereas the third building would require a one to two matching.

The experience of developing or assisting in the development of proposals for the National Aeronautics and Space Administration, National Science Foundation, and the Office of Education leads one to ask several questions. Perhaps the most serious question that naturally evolves is why one proposal stating the institution's aims and objectives cannot satisfy all agencies involved in supporting research facilities at universities. In the best of worlds, one might expect that the same proposal might be circulated to the various agencies involved, with one site visiting team spending 2 to 3 days on the campus and reporting to each of the agencies involved. One recognizes that each agency has its own directive from the Congress of the United States but at the same time one wonders whether some sort of common set of data could not be provided by the university along with its statement of need.

The second question that one might ask is whether the best design of a facility is obtained when funding is necessarily piecemeal. If the group at Georgia Tech responsible for the preliminary design of the Space Sciences and Technology Center had been certain that the Institute had in hand $3.4 million to construct the Center, I am not at all sure that the final design would be the one accepted. A related point is that in some state supported institutions final designs cannot be developed until all funds are in hand; thus delays of initiating construction of 1 to 2 years often result.

A third question relates to the complexity one might expect to encounter in seeking support for a science building which might house research that is health related, space related, and at the same time basic. Should the building also house faculty offices, undergraduate classrooms, and laboratories, as well as graduate instructional laboratories, proposals could be submitted to each of the agencies supporting research and teaching facilities. Proposals could be submitted to each of five Federal agencies. Each proposal would include some scheme of indicating what portion of the building was proposed for support and it would also include some statement of what portions of the building other agencies have been asked to support. This is not an unreasonable situation. One can only hope that some methods of simplifying proposals and reducing information called for might be considered during interagency discussions.

On the other hand, we at Georgia Tech are particularly grateful for the generous support we have received and hasten to answer questions of the sort raised above with the fact that State funds would have built less than half the facilities needed immediately. The developing cooperative arrangements between Federal agencies and universities in funding research and instructional facilities can be streamlined by more government-university discussions in which each tries to understand the problems of the other.

WINTER: Even after years of experience in the construction one continues to be awed at the sight of a large building under construction. When one considers the thousands of parts, numerous materials, and variety of trades all meshing together on a big construction project, it is incredible that so few mistakes are made.

With the assumption that enough money is available for a new facility, how does one get to the point where the contract is awarded to the lowest bidder? The way to begin planning seems to be with a written building program. A building program serves as the basic reference document in the planning process, especially for the architect. Grant application documents provide an ideal starting point as a source of information. Included in the building program ought to be general policy statements affecting planning, architecture, and the definition of areas of administrative responsibility. In addition, the document should include information regarding the nature of research to be conducted, functional relations, detailed mechanical, electrical, and structural requirements, and a detailed funding and budget program.

Once the program has been written and the usual process of preliminary meetings with scientists, NASA officials, appropriate administrators, and architects has taken place then the architectural planning can begin in earnest. One major institution uses the policy of requiring the architect to produce half a dozen schemes from which one is then selected. But this sort of trial-and-error method tends to be time consuming and costly. It seems preferable to spend a great deal of time in program planning and predrawing conferences so that the mechanics of architectural direction are clearly defined and the architect is not floundering with trial-and-error designing. It is important to remember, as drawings are begun, that architectural planning includes a creative facet. This creative facet should also have room for expression. Allow the architect sufficient time to let the building program and the creative process percolate before he actually begins drawings. Serious mistakes are made functionally and esthetically when the architect is forced to meet unrealistic deadlines. This fact is especially critical with complicated and expensive scientific facilities.

Architects often refer to what is called the "architectural trinity" of form, function, and cost. These are the basic elements in architectural planning, and most good buildings are a balance of these three factors. Obviously, the architect must produce a building that "works" for the occupants; he must do it within the established budget; and it ought to be of an architectural quality that has a lasting value. These goals are not always achieved but they are as important to the administrator and scientist concerned with a particular project as they are to the architect. When form, function, and cost are not kept in balance, the result may be ugly buildings that do not work at a high price. An example of a successful building is the Engineering Center now under construction at the University of Colorado. It won an architectural design award and, even better, came in under the budget. The turnkey cost was $20.00 per square foot, which is quite good for a combined academic and research facility. The NASA building now under construction on the campus should be equally as successful.

One aspect of research facilities often discussed, but which has become an overworked cliche, is functional flexibility. In a recent tour of several research and development installations along Boston's now famous Route 128, it was interesting to observe how organizations try to achieve functional flexibility in their physical facilities. Two organizations in particular were similar in many respects. Both were research-and-development oriented and both manufactured exotic products in rapidly changing markets. Yet, both approached the problem differently. One went all out with movable partitions and with utilities popping out every few feet from floors and ceilings. The other used concrete block partitions with an occasional utility chase. The approaches to the problem were almost opposite. Another example is a prominent architectural firm that often designs research facilities with an exoskeleton utility system. This system consists primarily of wrapping the utilities around the exterior of the building between the interior and exterior walls. No doubt for some research and laboratory activities such a design works very well. These examples illustrate that there are many ways to approach the problem. As you plan for flexibility, much, of course, depends on the activities that will be conducted in a particular space, but because no building can ever be planned that is completely flexible, perhaps the best that can be done is merely to make some assumptions about the specific project and try to strike a balance between current functional requirements, cost, and long-term assumptions of need. Beyond that functional flexibility is largely a state of mind.

Getting the project from program to completion obviously requires a great deal of collaboration. The lively art of coordination is often overlooked as a vital ingredient in construction programing. There is a tendency to assume that if everything else is done, coordination will automatically take care of itself. But, when dealing with numerous people all sharing some responsibility for planning the facility, coordination cannot be left to happenstance. Fortunately, agencies like NASA try to make the complexities of administration as easy as possible by working within an institution's existing operational structure by keeping red tape to a minimum and by using the problem-solving team approach. To have effective coordination, areas of responsibility must be defined and realistic schedules established. Preferably, responsibility for overall coordination should be assigned to one person. I think a system of coordination and assignment of specific responsibilities is especially important when planning a facility at educational institutions because colleges tend to be committee oriented. This orientation leads to a dispersion of responsibility. Committees operate best when there is someone else to do the work. The PERT system of coordinating and scheduling has proved to be very effective and is now widely used in the construction industry. It also has great possibilities for the planning phases of construction projects. The greatest asset of PERT is that it puts the burden of performance on the person who is responsible for a given portion of the work. This psychological pressure takes many of the problems out of coordination and scheduling. As a result, I would expect PERT or some similar system to begin to be an important part of most planning programs.

In general, planning and constructing a research facility on a college campus requires a special touch from that which characterizes most commercial or industrial installations. A college campus is a unique community requiring a unique physical setting: one which will help germinate the kind of creative response to problems that is so badly needed. The infusion of investment by such organizations as NASA tests the adaptability of each institution's planning programs, which are really nothing more than broadly based self-fulfilling prophecies. In building for research, it would be wise to keep in mind the need for balance in form, function, and cost. Frederick Low Olmstad, the father of landscape architecture, expressed it very well when he stated: "Beauty, like economy, must be strived for in public buildings."

BUCK: It has been my good fortune to be associated with the building of research facilities for a good many years. I have but three suggestions for consideration: square feet, speed, utilization and return.

(*1*) *Square feet.* Research facilities, the means and place to conduct research, are the hardest of all things to come by, no matter the source of funding. Building costs can vary from $18 a square foot to above $50. This depends upon usage and occupancy. Efficiencies can vary. No set rules, in my opinion, apply to such numbers. One rule is paramount: the rule of obtaining the most that is possible within a given funding for any occupancy or usage. While one must recognize the constraint of compatibility, architecture, and location, the experimenters and their architect engineer groups should welcome the challenge of trying to get the maximum facility the funding will permit.

(*2*) *Speed.* It has been said many times that the store of human knowledge doubles every 10 years. Research facilities are a means to an end, the increase of knowledge. When one views the time from the inception of the idea in the experimenter's mind, through the channels of university approval, through the channels of the government in this case, through the channels of design and design approvals, and finally through construction, one is truly dismayed and justifiably impatient with any unnecessary protocol-type delays or any low-gear effort. Urgency is not only implied, it is real. Further, this urgency should be felt by each member link of this chain.

(*3*) *Utilization and return.* Research facilities are but a means to an end, a means with which to do research, a means to provide the Nation with an increasing fund of knowledge, a means to provide the Nation with a better-trained manpower pool; no nation is more advanced than its people. Research facilities, hence, are one element of a closed loop system, with a continuous feedback to all elements on a continuing basis. As one example, NASA receives from the universities not only trained people and research information, but even information on how to build new and more advanced research facilities. This feedback also benefits industry and the universities. As a result, the Nation profits and I believe humanity profits as well.

Comments—Session VI

Van Dreal, *University of Oregon:* Dr. Levinthal, could you sketch briefly the relationship between your laboratory, the Instrumentation Development Laboratory at Stanford, and the investigators working under NASA grants who require instrumentation? Do you have any formal procedures?

Levinthal: No, we don't. Our laboratory does not pretend to be the sole or unique vehicle for instrument development within the School of Medicine. We do encourage collaborative projects with other departments, but the laboratory is primarily a vehicle for the principal investigator, Dr. Lederberg, in the Department of Genetics.

Gantt, *Johns Hopkins University:* As I listened to the earlier speakers, Chancellor Litchfield and Professor Simpson, I think it was, I thought I detected two opposite points of view which were rather definite as they were expressed. It seemed to me that there seemed to be two points of view in regard to a university's philosophy. Dr. Litchfield said that we were living in a new era, in which a university had to be oriented with respect to social action. Dr. Simpson seemed to favor a more old-fashioned approach. Are we living in the twilight of a past era or at present would there be any place in the university organized for social action for a budding Sir Isaac Newton, for example? As I understand Newton's career, he produced his most important works when he was not under any particular discipline in the early part of his life, whereas when he joined the administration and got grants from the government I believe that what he did in that era is not very highly valued.

Simpson: Essentially, I was attempting to demonstrate that in the universities we can continue the traditional role of the free investigator whether he be Newton or someone of an order-of-magnitude lower stature. I believe this is possible provided that the universities have set up within their structures suitable means of communication that enable the transfer of information between NASA and the investigator so as to provide a "buffer" between the investigator and NASA on administrative matters. I believe in many cases some of us in the scientific community are guilty of not understanding what is happening to us as a result of "big science", and we have not been asking for the kind of support which universities could provide in these matters. These provisions are to insure freedom for the scientific investigator. I also am concerned about one of the consequences of Chancellor Litchfield's comments. He has a very important point in strengthening the social role of the universities. I disagree that universities should organize as he suggests, but do believe that there are times when academic groups within the universities may temporarily organize for social action toward specific objectives. As an example, I recall an occasion at the end of World War II at Chicago. In 1945 there was a massive and effective effort by our faculty to abolish military control of atomic energy. This was an activity initiated by individuals in science, in law, and in political science, which resulted in the writing of a new Congressional Bill which provided for civilian control of atomic energy. This is a form of organized social effort on the part of individuals within a university. What I disagree with is the implication of the promulgation, from the university administration, of the goals and objectives which are to be achieved by individual investigators. This is where there is a discrepancy in philosophy and a substantial disagreement.

Page, Wesleyan University: It seems to me that we astronomers who thought we had something to do with space are facing a major change in our profession and that we have to consider our changing role in a university. I don't think that the role of the university has changed at all. Robert Maynard Hutchins at Chicago used to say that the University is a community of scholars, implying the kind of communication that has been stressed here. The difficulty is that we are divided up in departments and divisions which are not appropriate for the space age. There may be reason for changing our methods of instruction and changing our communication patterns within the universities. It may be appropriate for the geologists and the biologists and the physicists to work with the astronomers or vice versa. This may mean a major change in course structure and degree requirements. Astronomy certainly has gone through one major revolution with the introduction of spectroscopy, and the astronomer of 1850 would have a hard time in satisfying some of today's requirements. We seem to be faced with a major change in what we call astronomy or, at least, with a need for enlarging the field. I would think that what would be most helpful would be to encourage multidisciplinary research and teaching and I would hope that NASA would have this as one of its major objectives.

Kuiper: Dr. Simpson gave an example of the problem. Fortunately, nuclear physics belonged clearly in a department of physics. The science that was pressed with tremendous national effort, the development of a nuclear weapons during W.W. II, had a home; it belonged to physics.

Space science, Dr. Simpson remarked, is no science at all. There is, within the university disciplines, no natural home for space science. Maybe a new home has to be created. We should perhaps recognize the new divisions that are developing and create a home within the universities.

We have a tremendously powerful and active national space program, and there are no recognized disciplines which precisely correspond to this national activity within the universities. Many problems stem from this fact. Perhaps the scientists in the universities who are grumbling about the space program should make an effort to modernize their own institutions so that university disciplines would be reoriented to correspond to the new opportunities in research.

Nier: In regard to the question of allowing for the individual scientist, isn't it true that through some of the block grants that are related to the overall grants to institutions there are opportunities for individuals? Many of us who have tried to recruit students in a field where we have no active work at the present time find that this is rather difficult because the young people like to go to universities where everything is set up, where there is money available, and where they fit in rather than to an institution where there is a shortage of money. I think the result is that the rich get richer in certain areas and the poor get poorer. A system of block grants which gives an institution some discretion can help make up such deficiencies.

Bowhill, *University of Illinois:* With regard to establishing lines of communication among different departments, scientists usually communicate with those people with whom they have the greatest amount in common; frequently, this community of interest resides more outside of a particular institution, in perhaps 50 to 200 scholars or scientists with like interests. This community of interest is much more fruitful more frequently than the community of interest that can be found among scholars working even in the same general area of space science within the university itself. Is this a desirable or undesirable state of affairs? If it is undesirable, how can we change it?

Kuiper: I think that it would be of great importance to NASA and to the space program if professional standards within the university community were developed through precisely the kind of contact to which you refer; namely, I think I could foresee, for instance, that many hasty suggestions which now appear in print would never appear if there were the equivalent of a scientific society or group or association which would, in a friendly way, thrash out the problems. A lot of utter nonsense about the Moon and about space exploration would never be published if such an organization existed. The literature on the solar system is full of completely worthless material. It has created a great deal of confusion.

Holloway, *NASA:* With regard to Dr. Picha's comments, I know of no requirement for the submission of different proposals to the different agencies, say, five, in Washington, who might offer financial support for a building. I believe that any of these agencies would consider, without question, a proposal which included all requirements. All that would be necessary would be to include information to cover every agency's requirement in each proposal. I think there is no requirement for separate sight visits. All that is necessary to have only one site visit is to be sure that each site visit includes representatives from every agency which might consider your proposal. I suggest that this might be less than advantageous to many universities which might wish to deal with and which might be equipped to deal with, only one agency.

Finally, I would suggest further that identity of requirements in this business of Government consideration of university proposals for research or for training or for facilities comes very close to the first step to monopoly, with monopoly defined as the situation in which one person in Washington can say "No," and, if he says it, there is no place else to turn. I think the wisdom of embracing this should be seriously questioned. We believe that diversity of support of these enterprises by several Federal agencies, each motivated in a different way, and each based on different enabling legislation, is not only important but essential to the health of this kind of an enterprise if it is to survive over a number of years, to remain viable, and to offer universities the opportunity for the expression of their individual desires.

Appendix—List of Participants

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