SUMMARY REPORT

September 1970

NASA Grant NGF 22-009-021

CSR PR-9978-43

CENTER FOR SPACE RESEARCH
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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on

NASA FACILITIES GRANT NGF 22-009-021

[Formerly NsG(F)-8]

To The

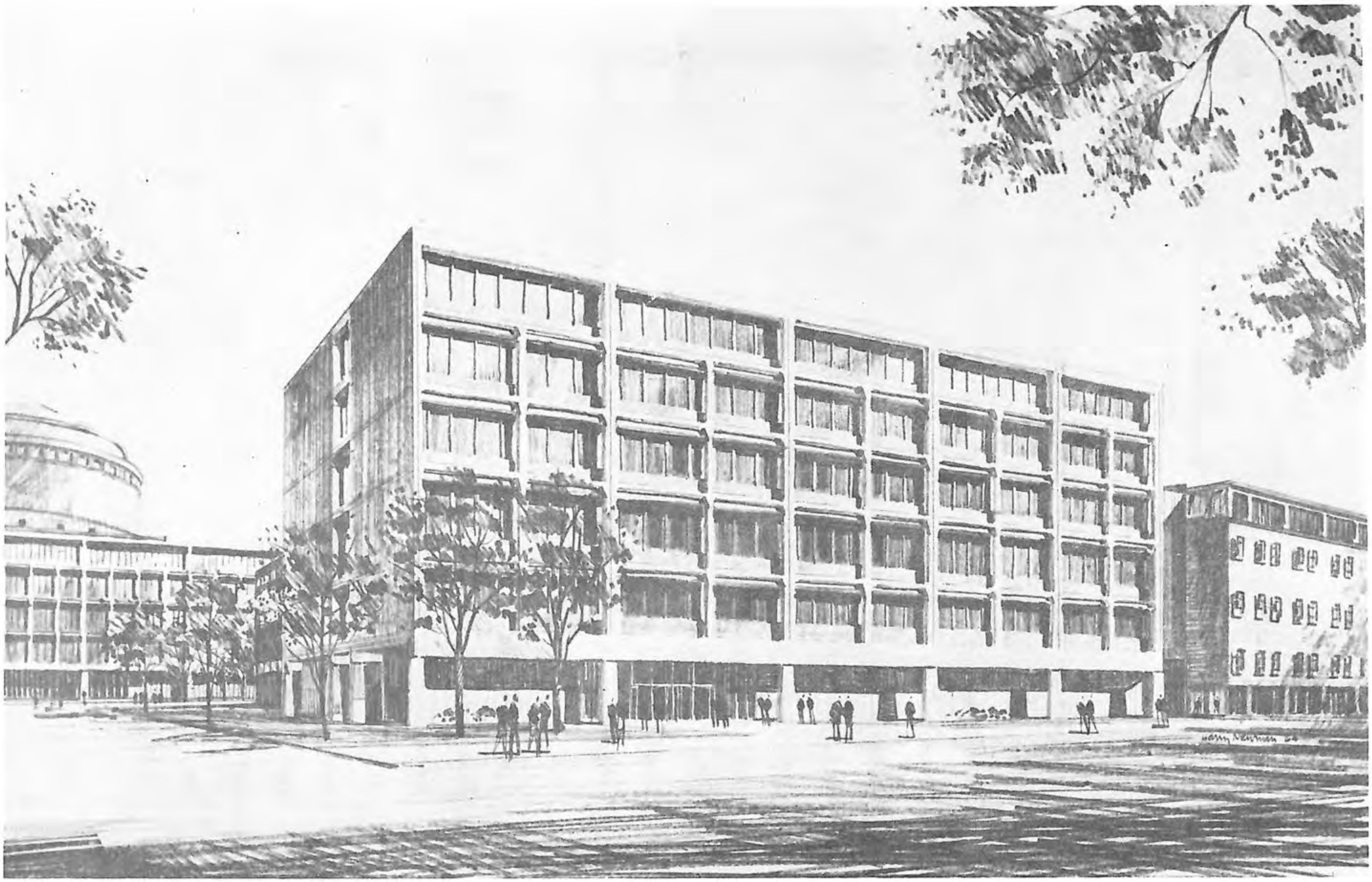
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Office of University Affairs

Washington, D. C.

Prepared by: Lawrence E. Beckley
Administrative Officer

Approved by: John V. Harrington
Director



Artist's drawing of new M.I.T. Center for Space Research to be built along Vassar Street.

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INTRODUCTION

This report represents a summary review of the planning and development of the Center for Space Research building facility at the Massachusetts Institute of Technology. It constitutes the final report on the National Aeronautics and Space Administration Facilities Grant NGF 22-009-021 which provided M.I.T. with a major portion of the funds used in the construction of the building. Interwoven in this description of the physical characteristics of the M.I.T. Center for Space Research are some insights into the motivations and institutional forces that have brought the Space Center to its present state of development.

THE NASA SUSTAINING UNIVERSITY PROGRAM

At the time of the creation of the National Aeronautics and Space Administration in 1958, there was recognition by the Congress of the importance of continued strong working relationships between the new space agency and the universities. The early phases of this developing effort consisted chiefly of an expanded program of project research which was largely designed to contribute directly to the fulfillment of NASA's primary mission. This mission included the following: ". . . the expansion of human knowledge related to phenomena in the atmosphere and space; physical operations in these media; and, the peaceful applications of this knowledge and these capabilities in support of national goals. . ."

A second stage of the NASA-university relationship evolved in 1961 with the establishment of the sustaining university program in which a specific purpose was delineated: "... to broaden the base of academic participation and training in space science and engineering in universities throughout the nation..." This new approach was centered upon the main theme of markedly increasing the supply of highly trained scientists and engineers and the fostering of new interdisciplinary relationships considered necessary for the fulfillment of the new national space goals.

Implementation of this program took effect in three areas which proved to have fundamental impact on the relationship of the university to the national space program. First, a strong program of graduate student fellowship support was provided under an extensive series of training grants. Next, a program of general research in the space sciences and engineering was established through the medium of block research grants for which the universities themselves provided overall direction and administration of the specific research efforts. Finally, a series of building grants were made to universities to provide for the development and centralization of the new research facilities in support of the desired expanded space research and training efforts.

M.I.T. participated in all three phases of this program, the building phase for which a description is provided in this report. Progress and technical reports submitted under Training

Grant NsG(T)-20 (later changed to NGT 22-009-020) have described respective activity at M.I.T. under these other phases of the overall program.

M.I.T. SPACE RESEARCH PROGRAM

NASA Facilities Grant NsG(F)-8 (later changed to NGF 22-009-021) was made effective on June 15, 1963, and provided $3 million toward construction of a Center for Space Research on the M.I.T. campus with the stipulation that not less than $1 million in matching funds be provided by M.I.T. for the total cost of the building. A Memorandum of Understanding, signed by the Administrator, National Aeronautics and Space Administration, and by the President of the Massachusetts Institute of Technology, and which became part of the agreement, related the terms and conditions by which the Institute intended ". . . to foster and conduct research in all areas of space-related sciences, bring to bear on this research the multidisciplinary efforts characteristic of a major university, and seek ways in which both the direct and the indirect benefits of such research can contribute to the economic, social, and general well being of the nation."

Much progress has been made toward these objectives. However, it should be said this progress has resulted largely from M.I.T.'s responsibilities and general tasks as a leading academic institution of learning in a rapidly developing technological society, rather than necessarily and specifically in response to the above charge.

New multidisciplinary and interdisciplinary relationships and combinations among faculty are usually the result more of changes in the surrounding general technology itself than of preplanned combinations of an arbitrary nature. There must be a certain degree of urgency and overriding common need before already heavily engaged faculty investigators will come to depend upon their colleagues in new and untried endeavors. The arrival of these new forces upon the scene is largely unpredictable, as was the space program itself. This leads one to question just how one plans in advance to have just the right combination of talents ready to meet some future and unknown need. Those professionals who appear to adapt most easily are those with strong grounding in the basics of science and technology. Also, the organizational structure best suited for response to these new challenges will emphasize functional flexibility. Therefore, the research facility best suited for a changing technological scene will then also emphasize flexibility in concept and configuration.

The establishment of the Space Center at M.I.T. certainly did not mark M.I.T.'s original entry into space-related research. The cosmic ray research, which was later to become the nucleus of a much expanded space research effort under NASA sponsorship, had been a well established program in the Institute's Laboratory for Nuclear Science under sponsorship by the Atomic Energy Commission. New navigational and guidance systems adaptable to space use represented a well advanced technology of the M.I.T. Instrumentation Laboratory as did the advanced research on space communications, re-entry phenomena, and radar astronomy at the M.I.T. Lincoln Laboratory. Both the Lincoln Laboratory and Instrumentation Laboratory programs had been largely the result of significant and long-standing sponsorship from the Department of Defense. The well known and early developments in plasma physics, radio astronomy, and communications theory by researchers of the Institute's Research Laboratory of Electronics clearly preceded the advent of the space program and again provided the solid base for on-going research for the new NASA programs in space communications to build upon.

The Department of Aeronautical Engineering had become the Department of Aeronautics and Astronautics in 1959 and had announced a widening of the scope of its teaching and research to include new disciplines such as the navigation and control of satellites and spacecraft, the design of manned space vehicles, and research into the related problems of man's first journeys into space. It introduced a new engineering science curriculum stressing, in greater depth, the subjects of physics, mathematics, fluid dynamics, and solid mechanics, and cited these as particularly suited to the preparation of undergraduate students for careers in aerospace research and development. Announcement was made in 1960 of the intended further organizational evolution of this Department into a new Center for Aeronautics and

Astronautics and its inclusion as an integral part of the M.I.T. Second Century Fund drive for capital funds for new buildings. Thus, with this program, a start had already been achieved in the raising of the necessary capital building funds for this new Center. The new NASA program benefited directly from this early groundwork at M.I.T.

Other important areas of space-related research were also well established throughout the Institute, and many of these became the building blocks for expansion under NASA and other Federal agency sponsorship in the overall national space mission as it developed in the 1960's.

The NASA Sustaining University Program with its impressive funding resources entered the M.I.T. research facility planning picture at this point in time with its three-part program of training grants, research funding, and new facility grants.

THE M.I.T. FACILITIES PROPOSAL TO NASA

Following preliminary discussions in the fall of 1962 between Mr. James E. Webb, Administrator, and Dr. Robert C. Seamans, Jr., Associate Administrator, of the National Aeronautics and Space Administration, and Dr. Julius A. Stratton, President, and Dr. Charles H. Townes, Provost, of the Massachusetts Institute of Technology, a formal proposal was submitted in April 1963 by the Institute for construction of a Center for Space Research building on the M.I.T. campus.

This proposal was accepted by NASA, and the formal grant documents were made effective June 15, 1963. In these documents agreements were reached that the costs of the new building were to be shared by the NASA sustaining university program at $3 million and M.I.T. at $1 million. The new building was planned to be integrated with the permanent on-campus buildings of the Institute, would encompass approximately 100,000 gross square feet of floor space, and would provide the necessary additional physical facilities for an appreciable part of M.I.T.'s program of space research. The new building was conceived as both a physical and an intellectual center to help bring together students, engineers, faculty, and support personnel in carrying out basic space-related research in many disciplines. It was to house programs for the design and construction of space probes for direct experiments in space and the reduction and analysis of space data obtained therefrom. The proposal went on to recount in some considerable detail descriptions of the many M.I.T. programs of on-going space research and the Institute's intent to make every reasonable effort to bring its variety of scientific and engineering disciplines to bear on the general field of space research; to explore mechanisms whereby results from the space program could be fed into industry and segments of the nation's economy; to expand the search for useful applications of the space program; and to measure the resulting economic and social impact on the nation as a whole.

An organizational structure for the new Center for Space Research was described in the companion proposal for sustaining university research funds which placed a Director (Professor John V. Harrington) in charge of the new Center and reporting in line responsibility to the Provost and in a staff capacity to a policy committee composed of senior academic administrative staff and faculty of the Institute. This committee included the following in its original membership:

Professor Gordon S. Brown, Dean of the School of Engineering
Professor William W. Buechner, Head, Department of Physics
Professor Charles S. Draper, Head, Department of Aeronautics and Astronautics
Professor John V. Harrington, Departments of Aeronautics and Astronautics and Electrical Engineering
Professor George R. Harrison, Dean of the School of Science
Professor Raymond Hide, Departments of Geology and Physics
Professor Max F. Millikan, Department of Economics and Director of the Center for International Studies
Professor H. Guyford Stever, Head, Departments of Mechanical Engineering and Naval Architecture
Professor Howard W. Johnson, Dean of the School of Industrial Management

Professor Charles H. Townes, Provost, served as a member (ex officio) of this committee and Professor Harrington was its chairman.

A Technical Committee, made up of senior faculty representing the various science and engineering disciplines, supported the Director in coordinating the overall research activities planned for the Center. The membership of this original committee included the following:

Professor Erik L. Mollo-Christensen, Department of Aeronautics and Astronautics

Professor J. Francis Reintjes, Department of Electrical Engineering

Professor Bruno B. Rossi, Department of Physics

Professor Nevin S. Scrimshaw, Head, Department of Nutrition and Food Science

Professor Robert C. Wood, Department of Political Science

Professor John V. Harrington, Director of the Center for Space Research (Chairman)

Mr. Lawrence E. Beckley served as Administrative Officer of the new Center for Space Research and as secretary to the policy and technical committees.

In the implementation of the research program of the Center, valuable assistance was afforded by Dr. Thomas L. K. Smull, Director of the Office of Grants and Research Contracts, NASA, and for the building program by Mr. Donald C. Holmes, Facilities Chief of the Office of Grants and Research Contracts, NASA.

After the formation of the new Center, an immediate search was launched for temporary quarters on or near the M.I.T. campus in which to build up a program of space research and to carry out the important task of formulating functional specifications for the new structure. A former industrial building, located two blocks north of the main campus, was acquired, one floor of which was renovated for the Center for Space Research which now for the first time became an independent entity with a home it could call its own. Soon a start was made in the new Center on the build-up of programs and staff for the Laboratory for Space Experiments which had the specific task of providing engineering design, construction, and assembly of payloads for space exploration. These early tasks included prototype designs for the Sunblazer spacecraft, cosmic ray payload assemblies for high altitude balloon flights and sounding rocket launchings, and interplanetary plasma experiments on the NASA IMP and Explorer series of satellite spacecraft.

During this period close associations were developed with the Experimental Astronomy Laboratory under the direction of Professor Winston Markey of the Department of Aeronautics and Astronautics. This group had underway promising programs of research in space navigation, sensing of terrestrial phenomena from high altitude aircraft, and other related studies. The Man-Vehicle Control Laboratory, under the direction of Aeronautics and Astronautics faculty--Professor L. R. Young, Y. T. Li, and J. L. Meiry, with NASA-supported research in man-machine interactions, was another group expressing an interest in cooperating with the new Center.

The Cosmic Ray Group of the Laboratory for Nuclear Science at M.I.T. proposed to transfer its activities under that laboratory to the Center for Space Research. A strong program of space research was already in being by this group under the leadership of such distinguished investigators as Professors B. B. Rossi, G. W. Clark, Dr. H. S. Bridge, and others. Payload engineering design and construction support for this group had formerly been provided by the Lincoln Laboratory and the Laboratory for Nuclear Science.

In addition to the above groups, research space and association with the new Center was also sought by the following: the Space Propulsion Laboratory, conducting research in gaseous nuclear rockets, hybrid rockets, and related topics under the supervision of Professors J. L. Kerrebrock, G. C. Oates, M. A. Hoffman, and J. E. McCune of Aeronautics and Astronautics; the Fluid Dynamics Laboratory with on-going research in the gas dynamics of rarefied atmospheres under the supervision of Professors L. Trilling and H. Y. Wachman of Aeronautics and Astronautics; elements of the Aeroelastic and Structures Research Laboratory with research interests in solid mechanics and hypervelocity impact under the supervision of Professors E. A. Witmer, J. W. Mar, and T. H. Pian of Aeronautics and Astronautics; elements of the Electronic Systems Laboratory engaged in research on new circuitry developments for space electronics systems under the supervision of Professors J. F. Reintjes and M. L. Dertouzos of Electrical Engineering; a group with social science interests and programs dealing with the economic and international aspects of space research under the supervision of Professor R. C. Wood of the Department of Economics; a research group led by Professor A. Rich of the Department of Biology with studies underway on extraterrestrial life forms; and, finally, a research group of the Department of Nutrition and Food Science engaged in studies of the nutritional aspects of manned space flight.

The foregoing describes in general terms those research groups which ultimately moved into the Center building when it was completed in the fall of 1967.

Actually, discussions were held with still other groups engaged in space-related research during the design stages of the building in late 1963 and early 1964, but for a number of diverse reasons, the final selections came down to the groups described above.

As of the date of this report, minor shifts have taken place in these affiliations within the Space Center but these represent no greater changes than would normally be expected in any similar evolutionary process at the Institute.

THE CENTER BUILDING DESIGN CRITERIA

Inasmuch as the new building was to be integrated with existing and newly planned permanent campus buildings of the Institute, certain constraints existed early in the evolution of the design. The site selected limited the building width to a maximum of about 78 feet; overall height constraints dictated a height of not more than six floors.

These, combined with a total expected floor area of about 100,000 square feet, produced a building length of about 190 feet. The underground conditions of deep soft clay and silt dictated a pile foundation. The required bridging of dual 24-inch underground water mains ruled out a single reinforced concrete slab foundation. Pile clusters were required together with a carryover reinforced concrete beam structure that was ultimately carried upward to form the main structure of the building. A wider building was desired which would have allowed a double corridor arrangement with offices on the perimeter and laboratory and service areas in the central portion of the building. This would have more nearly met the need for a greater proportion of office space than could be obtained with the single corridor design. However, this was compensated for somewhat by making part of the central area into student office space and placing additional offices along the outer walls in some of the larger laboratories.

With the overall building shape and proportions established, the next major consideration involved the decision making related to assignment of research space to specific user groups. As has been pointed out earlier, more space research was already underway at the Institute than could be accommodated in the new building to say nothing of expected future growth. The program objectives required a multidisciplinary character in the research. Immediately then, an important decision was thrust upon the building planners. It became necessary either to accommodate whole groups while leaving out others or, alternatively, to include a series of critical size or representative sample groups from each of the several disciplines. A combination of these factors was ultimately agreed upon. Some whole groups that could be reasonably accommodated, such as the Cosmic Ray Group, the Man-Vehicle Laboratory, and the Fluid Dynamics Laboratory, were provided for. In the cases of the remaining eight or nine groups, critical size elements were provided for. In all of these decisions an important factor concerned the availability of other permanent space elsewhere at the Institute. With occupancy of the building more than two years away, problems were also raised about the changing nature of the various research programs, turnover among the several principal investigators, and the changing character of engineering and scientific research itself in terms of facility needs. As a result, it was decided that expensive and inflexible special purpose facility items should be kept to a minimum. Movable partitions were recommended wherever practicable, and particularly in the laboratory areas. In this respect, compromises were necessary right from the beginning. The basic structural arrangement in the building, already largely dictated by the site, necessitated a centrally located, longitudinal double-beam configuration about sixteen feet wide. This gave two areas on each side of the building's central core with dimensions of about 28 feet by 190 feet and free of columns. Five equally-spaced vertical service flues were provided in the central structural core along with the elevators, stairwells, toilets, and other service facilities. The remaining flexibility in arrangement was reduced at this point to the location of partitions dividing the long, longitudinal spaces into offices and a corridor on one side, and laboratories and some offices on the other.

Since the long dimension of the building ran approximately east to west, the north window wall was chosen for the principal offices. This selection then placed the building corridor between the offices on one side and the longitudinal core structure on the other. With the laboratory areas now located on the south wall, direct sunlight exposure on that wall, plus the need to make maximum use of wall space in the laboratories, strongly influenced the decision to incorporate a solid outer wall with a minimum of open window space.

Early in the design, a general Institute policy decision had been made to use a window wall module dimension of 9.5 feet. This fixed office width dimensions at 9.5 feet or multiples thereof. The location and width requirement of the corridor and the central core structural design fixed the office depth dimensions. The modular dimension of 9.5 feet or multiples thereof also figured in the dimensions of laboratory space. However, later experience showed that this factor did not appreciably affect the general workability of the desired laboratory layout configurations. Most needs were met without serious compromise. However, it must be stated that the resulting office configurations were less than optimum and generally too small. From the experience in this building design, an office depth of not less than about thirteen feet coupled with selective widths of ten, fiften, and twenty feet would have more appropriately suited the variable needs of the Space Center faculty, research staff and student occupants.

The decision to incorporate air conditioning, which was in accord with the general plans of the Institute for all new campus buildings, produced a quieter and cleaner building in which to carry out research on a year-round basis as well as supplying an essentially dust-free laboratory environment so important to much of the research activity in the Space Center. This feature has proved repeatedly to have been a real advantage to some of the more delicate instrument-type research projects as well as to those having other special environmental requirements. In locations where objectionable odors are produced, such as the animal laboratories in the life science research areas, an air pressure differential is maintained at all times such that the odors produced are carried out through the exhaust system. Air exhausted from these areas is not reused as is the case in much of the remainder of the building.

A harder decision concerned the choice of using a four-inch cinder block interior wall construction in lieu of demountable wall panels. The latter were recognized as being more easily changed, but were also considered more expensive, had poorer sound transmission properties, and were not conducive to the easy mounting of electrical, plumbing lines and laboratory equipment. The final decision went to the cinder block wall. However, experience has shown that this type of wall somehow manages to resist change and thus discourages rearrangement of spaces even when reasonably justified. For a changing program requiring fairly frequent rearrangement of spaces, the demountable wall would probably have still been the best choice in the long run, at least for the general laboratory areas.

The foregoing comments have been factual and to the point of perhaps offering advice useful for future building designs having similar use patterns. Evidence would indicate that some of the problems cited above have already led to better solutions in subsequent new buildings being used for similar purposes at M.I.T.

As a matter of record, the completed building has evoked overall favorable comment in terms of its general appearance and as a comfortable and efficient place to work and to teach. Its meeting rooms and classrooms have been in rather constant demand. Its offices and laboratories have been well populated with a variety of space research activities. The only evidence of less than full capacity use of all laboratory spaces appears to have been more related to the changing nature of the space research program itself, induced by varying budgetary and program considerations rather than by any deficiency in the building design. At the time of the writing of this report, the national space program was being subjected to a severe realignment of program objectives with resultant uncertainties cast on future sponsorship for many research projects for which the underlying foundations of basic research had been thought to have been well laid. Again, all this emphasizes the importance of deliberately and resolutely designing in flexibility in any such new building design and of strongly resisting the temptation to incorporate expensive special purpose equipment features and facilities that may have limited useful life spans.

THE COMPLETED BUILDING AND COST TABULATIONS

The selection of the building architect had been made by the Institute on the basis of the assignment of segments of the M.I.T. campus to each of several qualified architects. The objective of this procedure was to insure architectural compatibility of adjacent structures on the campus to the maximum extent practicable. The firm of Skidmore, Owings and Merrill, Chicago, Illinois, was designated to provide architectural services. Mr. Walter A. Netsch, Jr., was assigned as Principal and was assisted by Mr. Albert Lockett.

The completed Center for Space Research building at the Massachusetts Institute of Technology.

The preliminary design of the building was started in the summer of 1963 and the preliminary plans were submitted by the architect to M.I.T. in December 1963. Copies of these plans were sent to NASA in January 1964. A detailed building budget was established by M.I.T. in February 1964. Layout plans and specifications supplied by the architect were reviewed by M.I.T. in April 1964 and further reviewed among the architect, M.I.T. representatives and NASA representatives at the Goddard Space Flight Center in May 1964.

Detailed plans and specifications for the general construction contract were completed and made ready for prospective bidders in April 1965. Formal bids were received from eleven firms on the due date, May 1965. The lowest bid was about ten percent higher than the estimate plus contingency provided for the general construction contract. This was a period of sharply rising building costs. The high bids forced a hard decision to try to preserve the available low bid rather than risk a long delay and even higher costs for essentially the same overall building design. Many alternatives in the design were dropped at this point which resulted in a less than optimum final product. For instance, nearly all of the ceiling tile was omitted throughout the building, and this later proved to be an unfortunate decision in terms of building noise control. Experience has shown that this noise control is vital in the normal use of the building. Other internal building features of a more subtle nature were downgraded in this round of modifications despite the fact that the M.I.T. portion of the building budget was increased to compensate partially for the overrun in estimated costs.

Approval to proceed with the building construction was received from NASA in July 1965, and the general contractor, Jackson Construction Company, Inc., was authorized to proceed on July 30, 1965. The contract construction period was designated at 620 calendar days, or completion by April 1967. Various delays occurred during the building construction, some due to delayed material deliveries but principally concerned with the extra time needed for piling and foundation work. The first occupancy of the building took place in December 1967 and the building was essentially in complete operation in February 1968.

The original estimated cost for the Center for Space Research building project was \$4 million with \$3 million to be provided by NASA under building grant NSG(F)-8 (later changed to NGF 22-009-021) and \$1 million from M.I.T. The original general construction contract with the Jackson Construction Company, Inc. was for \$3,334,100 and the final total value after all changes was \$3,504,038.88. The final total cost for the entire project was \$4,529,767.79 of which \$1,529,767.79 was provided by M.I.T. The tabulation of these costs with a breakdown into appropriate categories is shown in Table I.

TABLE I. M.I.T. CENTER FOR SPACE RESEARCH

BUILDING COSTS

NASA/M.I.T.	March 1964 M.I.T. Budget	July 1965 After Bids	September 1969 Final Costs
Construction contract	$3,280,000	$3,334,100	$3,504,038.88
Central chilled water facility	--	226,000	226,000.00
Architects and engineers fees	350,000	270,000	270,000.00
Utilities	80,000	125,000	107,729.59
Site development	--	--	--
Fixed equipment	--	--	--
Furnishings	65,000	--	--
Surveys, borings and testing	15,000	20,000	19,149.32
Supplementary construction	20,000	--	--
Miscellaneous	5,000	--	--
Resident engineer and inspection	10,000	--	--
Moving	25,000	--	--
Contingent	150,000	24,900	--
Total	$4,000,000	$4,000,000	$4,126,917.79

Table I, continued

Supplementary M.I.T.			
Other architect and engineering fees	--	$ 55,000	$ 97,762.33
Utilities	--	105,000	140,091.91
Resident engineer, salaries and benefits	--	10,000	9,252.95
Supplementary construction costs	--	40,000	3,801.98
Furnishings	--	65,000	75,634.73
Contingency	--	25,000	--
Moving	--	--	29,860.11
Materials and services and Physical Plant expense	--	--	19,314.61
Equipment	--	--	16,753.81
Miscellaneous	--	--	10,377.57
Total	$ --	$ 300,000	$ 402,850.00
Project Total	$4,000,000	$4,300,000	$4,529,767.79

DEDICATION OF THE BUILDING

Formal dedication of the new Center for Space Research Building took place on April 25, 1968. The program for this memorable occasion is printed on this and the following pages. The talks given by invited guests and members of the M.I.T. community are contained in this section of the report.

PROGRAM

8:30 a.m.	Kresge Auditorium Registration and coffee
9:00 a.m.	Report: Selected Research Activities of the Center for Space Research
	Opening remarks Jerome B. Wiesner, Provost, M.I.T.
	Introduction John V. Harrington, Director of the Center for Space Research, M.I.T.
	Speakers
	Herbert S. Bridge Professor of Physics, M.I.T.
	William L. Kraushaar Professor of Physics, University of Wisconsin
	Winston R. Markey Professor of Aeronautics and Astronautics, M.I.T.
	Bruno B. Rossi Institute Professor, M.I.T.
	Nevin S. Scrimshaw, Head of the Department of Nutrition and Food Science, M.I.T.
	Eugene B. Skolnikoff Professor of Political Science, M.I.T.

12:30 p.m. Julius Adams Stratton Building
Informal reception for delegates

1:00 p.m. Julius Adams Stratton Building
Dedication luncheon for delegates

Introduction
James R. Killian, Jr.
Chairman of the Corporation, M.I.T.

Remarks
James E. Webb, Administrator
National Aeronautics and Space Administration

Response
Howard W. Johnson
President, M.I.T.

John V. Harrington, Director of the
Center for Space Research, M.I.T.

3:00 p.m. Center for Space Research
Informal reception and open house

THE CORPORATION

Vannevar Bush
Honorary Chairman

James R. Killian, Jr.
Chairman

Howard W. Johnson
President

Joseph J. Snyder
Vice President and Treasurer

Walter Humphreys
Honorary Secretary

John J. Wilson
Secretary

Life Members

Bradley Dewey
Vannevar Bush
James M. Barker
Thomas C. Desmond
Marshall B. Dalton
Donald F. Carpenter
Thomas D. Cabot
Crawford H. Greenewalt
Lloyd D. Brace
William A. Coolidge
Mervin J. Kelly
Robert C. Sprague
Charles A. Thomas
David A. Shepard
George J. Leness
Edward J. Hanley
Robert A. Lovett

Cecil H. Green
Horace W. McCurdy
John J. Wilson
Gilbert M. Roddy
James B. Fisk
George P. Gardner, Jr.
Robert C. Gunness
Russell DeYoung
William Webster
William B. Murphy
Laurance S. Rockefeller
Robert H. Winters
Uncas A. Whitaker
Julius A. Stratton
Luis A. Ferré
Semon E. Knudsen
Robert B. Semple

Life Members, Emeritii

Walter Humphreys
Alfred L. Loomis
Harlow Shapley
Ralph E. Flanders
Horace S. Ford
Walter J. Beadle

Duncan R. Linsley
Irving W. Wilson
Harold B. Richmond
Ralph Lowell
Gwilym A. Price
George M. Humphrey
James H. Doolittle

A Note about the Center for Space Research at M.I.T.
(From the Dedication Program and Brochure--April 25, 1968)

The branches of science and engineering involved in space research comprise many disciplines which, in the past, have rarely been called upon to pool to so great an extent their respective resources in the achievement of a common vital goal. Astronomy, a science as old as man himself, has had a startling rebirth brought about by new and seemingly limitless possibilities for gathering new facts about our universe. The space age has demanded an almost explosive development of exacting engineering techniques to carry man into space and to control his environment: new materials and structural methods to meet changing constraints imposed by weightlessness, radiation and vacuum considerations, complex sensors to measure a variety of interplanetary phenomena by new means and to new accuracies, improved systems for data storage, retrieval and transmission, severe reliability standards and microminiaturization of components and systems, man-machine interaction studies of great sophistication and importance, and many others. The new physical facts and technical knowledge being generated by the space program in an ever widening stream are not only revising man's long-standing concept of the near solar system but are also destroying scientific theories of long standing in many fields. New theories are being demanded to replace the old. The understanding that will undoubtedly come from these new theories inevitably will bring about startling and fundamental changes in man's concept of his environment and himself.

The programs to establish a Center for Space Research at the Massachusetts Institute of Technology evolved from several urgent considerations: first, the desire to broaden the interdisciplinary horizons of researchers to meet the new technological challenges of man's foray into space; second, through the creation of strengthened programs in space-related graduate education and research to encourage a significant increase in the number of graduate students in this new field; and third, through this increased training of qualified scientists and engineers to help this country excel in space exploration.

Space research is of concern to almost every school and department of the Institute and represents a significant portion of sponsored research in our departmental and interdepartmental research laboratories. While each of these has its own special interests and goals, many existing areas of mutual interest and interdependence have already evolved into joint programs of space research, particularly in the physical sciences and several branches of engineering. On the horizon can be seen emerging a clear indication of a similar cooperation between the life sciences and several other fields of engineering. The social sciences, while not directly involved in the development of space experiments, have had a vital interest in the interaction process between the scientist and the engineer, in the general impact of the new associations of science and engineering on the course of space research and, in turn, in the latter's effect on the nation's economy and its international relations. In the more distant future, as large manned spacecraft venture farther into the solar system and the planets become accessible to man and his works, the role of the social sciences will undoubtedly become a more central one.

Of particular interest in the development of space research at M.I.T. has been the reaction of the typical physical scientist and engineering faculty member as each looks upon this new field of space research. Generally speaking, the physical scientist, bent on the discovery of new physical parameters or phenomena concerning the universe, would like to look to his engineering faculty colleague for assistance in the solving of very difficult engineering problems of space payload and sensor design. While the engineering faculty member may well be intrigued with this prospect and undoubtedly could help, he will do so only if the involvement stimulates his own research as well as his own professional development. New information being sought by such interdisciplinary efforts must have wider implications--implications and results that can be applied to advance the state of the art in the field of <u>each</u> of the principal collaborators, <u>or</u> to have such important ramifications to society as a whole so as to transcend this individual need.

Since April, 1963, the Center has been charged with the administration of a National Aeronautics and Space Administration (NASA) Sustaining University Grant, NsG-496. These funds in sizeable proportions have been devoted to the support of space-related basic research at M.I.T. in the various physical, life and social sciences and in the engineering disciplines. With the general guidance of the faculty policy and technical committees, they have been allocated for new and deserving research, particularly that of young faculty members. The availability of these funds has been of tremendous importance to the growth and continuity of space research at the Institute. General funds of this sort are invaluable in providing initial exploratory support for promising new ideas. They provide a vital source of support, particularly in the engineering disciplines, for advanced state-of-the-art exploratory studies for which sponsorship from among the established research agencies is very difficult to obtain. They provide also a most important means for underwriting the development of mutual interests and communication between the various disciplinary groups having an interest in space research. New space research projects at M.I.T., having grown from this form of support and subsequently sponsored by separate Federal agency program funds, have in a large measure retained an association with the Center. The indefinite continuation of this type of funding, by which the Center's administrative facilities can be used to substitute for those that would be necessary in the sponsoring agency itself to support 30 to 40 individual grants, would appear to have great advantage in efficiency and flexibility.

The Growth of Space Research at the Center

The Center was formally organized in April, 1963, with the receipt of the first installment of research funding from the National Aeronautics and Space Administration under sustaining university grant NsG-496. Dr. John V. Harrington, then Head of the Radiophysics Division of the M.I.T. Lincoln Laboratory, was appointed the first Director. Policy and technical advisory committees were formed for guidance of the new Center. Soon afterward, the Institute consummated negotiations with the National Aeronautics and Space Administration for a facilities grant, NsG(F)-8, in the amount of $3 million and entered into a Memorandum of Understanding concerned with the future use of the Center for Space Research building and facilities. M.I.T. subscribed $1 million from the Second Century Fund as participating funds for the building.

Significant space research activities were well underway at M.I.T. at the time of the formation of the Center. Therefore, the sustaining university funds were organized and distributed in a manner designed to strengthen areas where present funding was insufficient and to initiate new programs in pertinent disciplines having little or no support. Gradually, what was considered a balanced program of space research was evolved. Early in the program, a Laboratory for Space Experiments was formed, whose function was to conduct engineering research on a small solar probe (later named Sunblazer) and to provide payload engineering design support for several faculty-principal investigators at M.I.T. The growth of this laboratory has been particularly significant, and present research program funding for its activities has reached a level of about $1.6 million per year. The laboratory is now engaged in engineering and development of a number of payloads for NASA space programs in conjunction with several groups at the Institute.

The largest of these groups, in terms of direct space research activity for which the Center provides facility, administrative, and program support, is the Cosmic Ray Laboratory (formerly part of the Laboratory for Nuclear Science). This group has a rather extensive space research program underway that is concerned with interplanetary plasma measurements, studies of galactic x-rays and solar physics. The total program level for this group is about $850,000 per year. The research is directed by Professors Bruno B. Rossi, Herbert S. Bridge, George W. Clark, and other faculty, all of the Department of Physics. Projects currently underway include payload developments for the NASA OSO-H (orbiting solar observatory), Anchored IMP (orbiting moon satellite), IMP H&J (high orbit earth satellites), x-ray sounding rockets, Mariner and Pioneer probes and others in the planning stages.

Other groups housed in the Center building and drawing on administrative support by the Center include the Experimental Astronomy Laboratory, the Man-Vehicle Control Laboratory, the Space Propulsion Laboratory, the Fluid Dynamics Laboratory and elements of the Aeroelastics and Structures Research Laboratory, all laboratories of the Department of Aeronautics and Astronautics. Similarly accommodated in the Center building are elements of the Electronic Systems Laboratory, engaged in space electronics research, and a Nutrition and Food Science group conducting research on nutritional problems in space feeding. A small group to carry on social science studies related to the space program is expected to move into the building in the fall of 1968.

The Center also provides program funds and administrative support for several faculty members of the Department of Physics conducting research in the general field of astrophysics, and to an Electrohydrodynamics Laboratory group, located in the Department of Electrical Engineering, whose work has application to space propulsion.

The overall sponsored research budget of the Center for fiscal 1969 is projected at about $4 to $5 million per year. When fully occupied, the Center building will include approximately the following personnel: Faculty--40, Visiting and Research Staff--60, Students--100, and Support Personnel--70, for a total of approximately 270. Additional personnel connected with sponsored research of the Center are housed elsewhere at the Institute and number approximately 80 persons.

The Center Building

The new building provides approximately 100,000 gross square feet of air-conditioned floor space for the Center for Space Research activities. There are laboratory areas for 13 separate research groups and office spaces for about 200 personnel. Included in the building are four classrooms, a space science library and reading room, a functions and seminar room, and administrative and service support facilities for the Center personnel and program.

The research program of the Center is sponsored primarily by the National Aeronautics and Space Administration through the Headquarters Offices of: Space Science and Applications, Advanced Research and Technology, Tracking and Data Acquisition, and University Affairs. Other program sponsorship comes from the Goddard Space Flight Center, the Ames Research Center, and the Electronics Research Center. A modest level of research funding has come from the National Science Foundation, the Atomic Energy Commission, and the basic research offices of the Department of Defense.

While the research which will be pursued in the new facilities has a general character implied by the interests of the groups previously listed, some specific topics include: evolution of the universe, origin of cosmic rays, solar physics, physics of the interplanetary medium, transmission of electromagnetic signals through a dispersive medium, gas dynamics of rarefied atmospheres, gas-solid interface reactions, kinetic theory of plasmas, propulsion by gaseous nuclear rockets and hybrid rockets and other forms, gravitational theory, verification of the general theory of relativity, space navigation, advanced terrestrial sensing techniques, nutritional aspects of manned space flight, information transfer in prebiological environments, social aspects of the space program on the government and the national economy and international relations, man-machine interactions and control, hypervelocity impact, and aerothermoelastic effects on space flight structures.

The research program of the Center represents a substantial fraction of the total space research activity of the Institute but by no means all of it. Space research is such a broad field, drawing on so many separate disciplines, that it would be virtually impossible and probably not desirable, particularly at a university, to gather these efforts into a single administrative or spacial entity. Attempts at such rigid organization of research inevitably conflict with the traditional freedom accorded the academic researcher and the interest and responsibility of the departments themselves for their faculties' research. The necessary compromise has been to attempt to gather instead research groups of at least critical size from pertinent disciplines so that the desired interaction can proceed on a representative basis, the lines of communication between the larger segments are established, and the research activity of each group in the Center is of at least a significant size and of promising productivity.

Finally, man's venture into space is only a short decade old. The broad-scale impact of space exploration on the nation's economy, growth, and international relations on the one hand and the contributing further involvement of academic institutions such as M.I.T. on the other, has yet really to be measured. As the space program evolves to the point at which the technology it develops and the scientific facts it unfolds lead to the benefits which history suggests must follow, and which are already becoming visible in the form of improved terrestrial communication, navigation and weather prediction, then we trust that this Center for Space Research which we dedicate today will permit M.I.T.'s faculty, staff and students to contribute significantly to the further exploration of space and ultimately to the benefit of all mankind.

FACULTY COMMITTEES FOR THE CENTER FOR SPACE RESEARCH

(From the Dedication and Program Brochure, April 25, 1968)

Policy Committee

Robert A. Alberty
Professor of Chemistry
Dean of the School of Science

Raymond L. Bisplinghoff
Professor of Aeronautics and Astronautics
Head of the Department

Gordon S. Brown
Professor of Electrical Engineering
Dean of the School of Engineering

Albert G. Hill
Professor of Physics

Max F. Millikan
Professor of Economics
Director of the Center for International Studies

William F. Pounds
Professor of Management
Dean of the Alfred P. Sloan School of Management

Frank Press
Professor of Geophysics
Head of the Department of Geology and Geophysics

Ascher H. Shapiro
Ford Professor of Engineering
Head of the Department of Mechanical Engineering

Jerome B. Wiesner
Institute Professor
Professor of Electrical Engineering
Provost

Herbert S. Bridge
Professor of Physics
Associate Director of the Center for Space Research

John V. Harrington, Chairman
Professor of Aeronautics and Astronautics
Professor of Electrical Engineering
Director of the Center for Space Research

Technical Committee

Wilbur B. Davenport, Jr.
Professor of Electrical Engineering

Jack L. Kerrebrock
Professor of Aeronautics and Astronautics

Winston R. Markey
Professor of Aeronautics and Astronautics

Bruno B. Rossi
Institute Professor
Professor of Physics

Nevin S. Scrimshaw
Professor of Nutrition
Head of the Department of Nutrition and Food Science

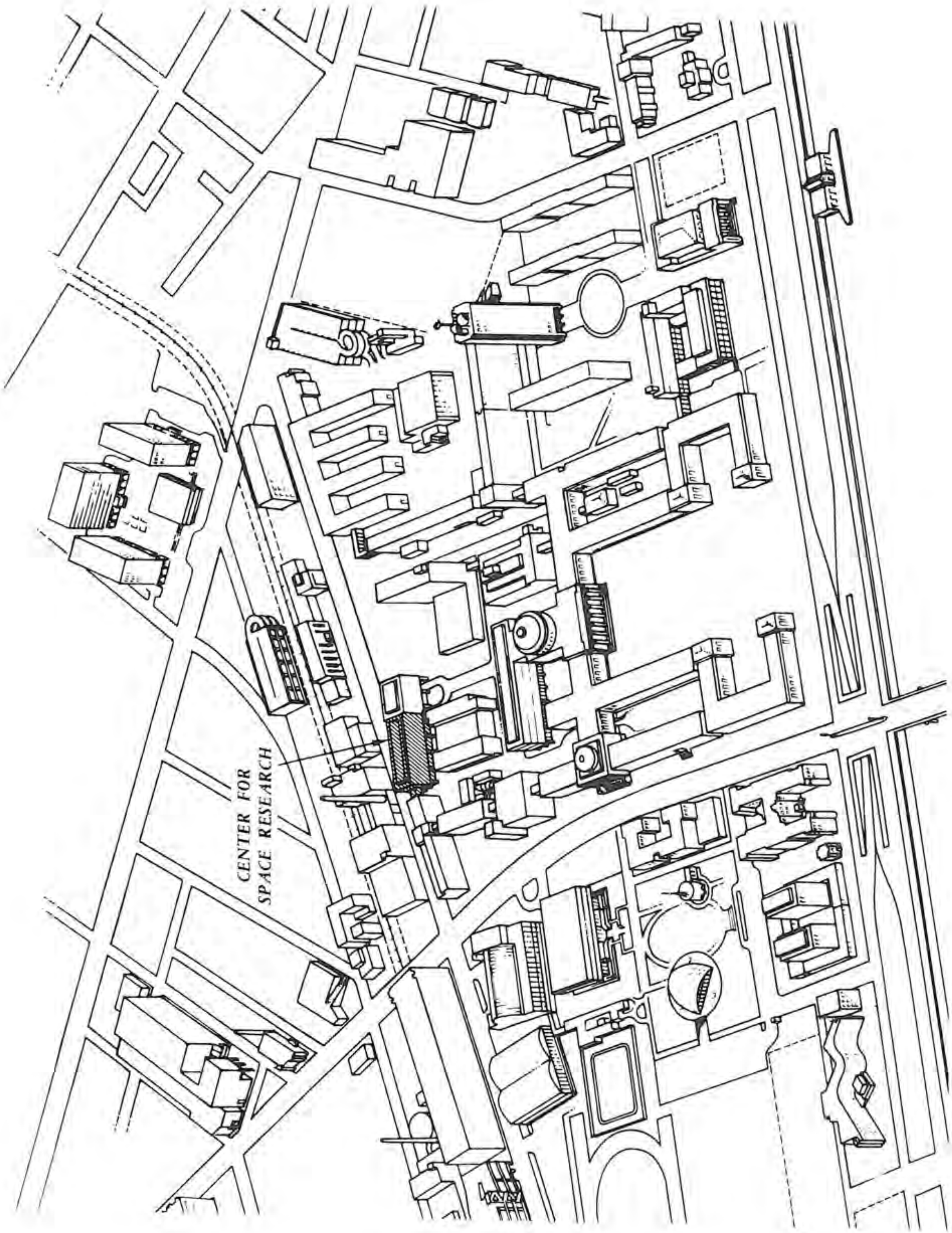
Eugene B. Skolnikoff
Associate Professor of
Political Science

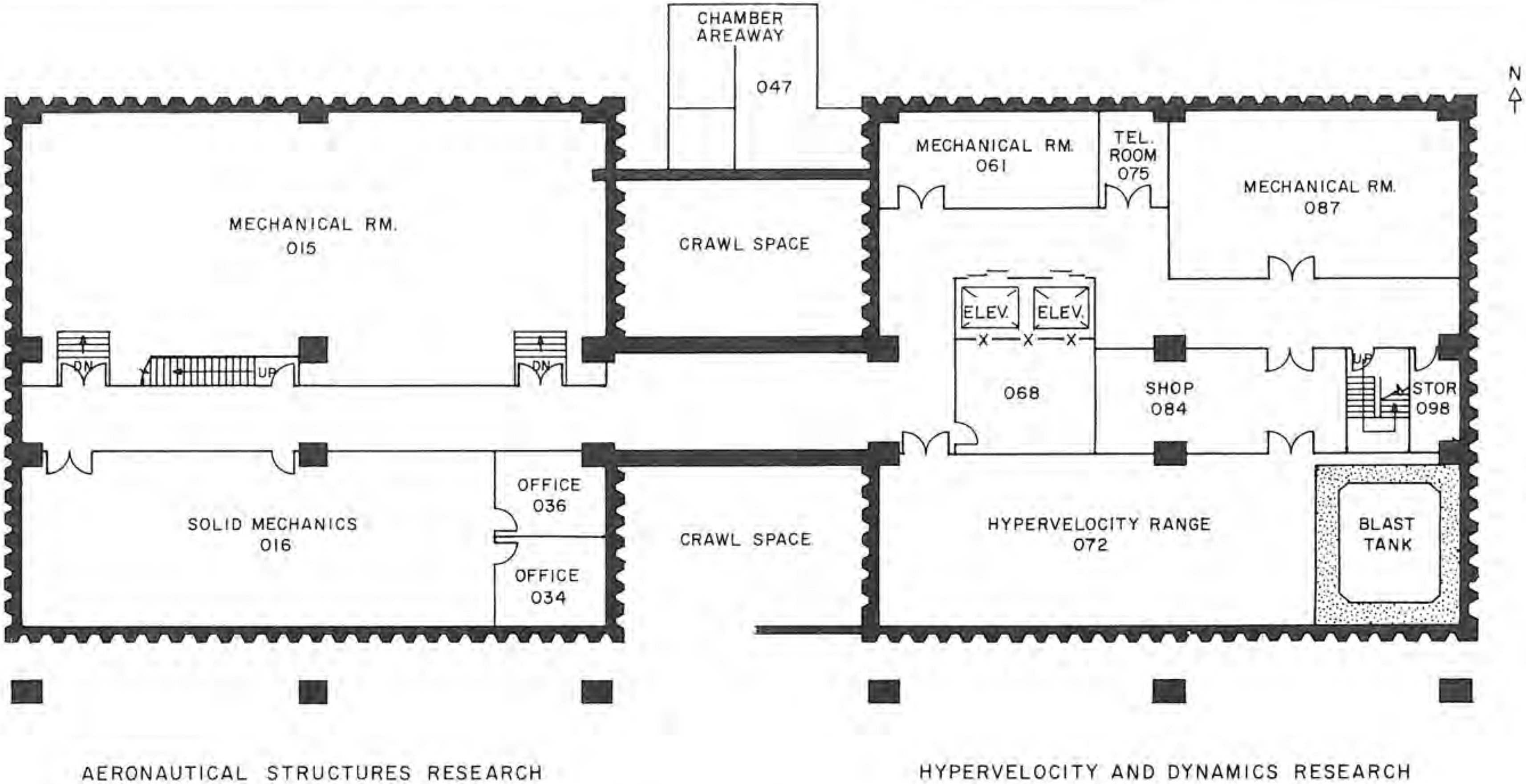
Herbert S. Bridge
Professor of Physics
Associate Director of the
Center for Space Research

John V. Harrington, Chairman
Professor of
Aeronautics and Astronautics
Professor of
Electrical Engineering
Director of the
Center for Space Research

SITE AND FLOOR PLANS

The following nine figures show, respectively, the location of the Center for Space Research building on the M.I.T. campus and the detail layout and disciplinary use of the basement through roof levels.


CENTER FOR
SPACE RESEARCH



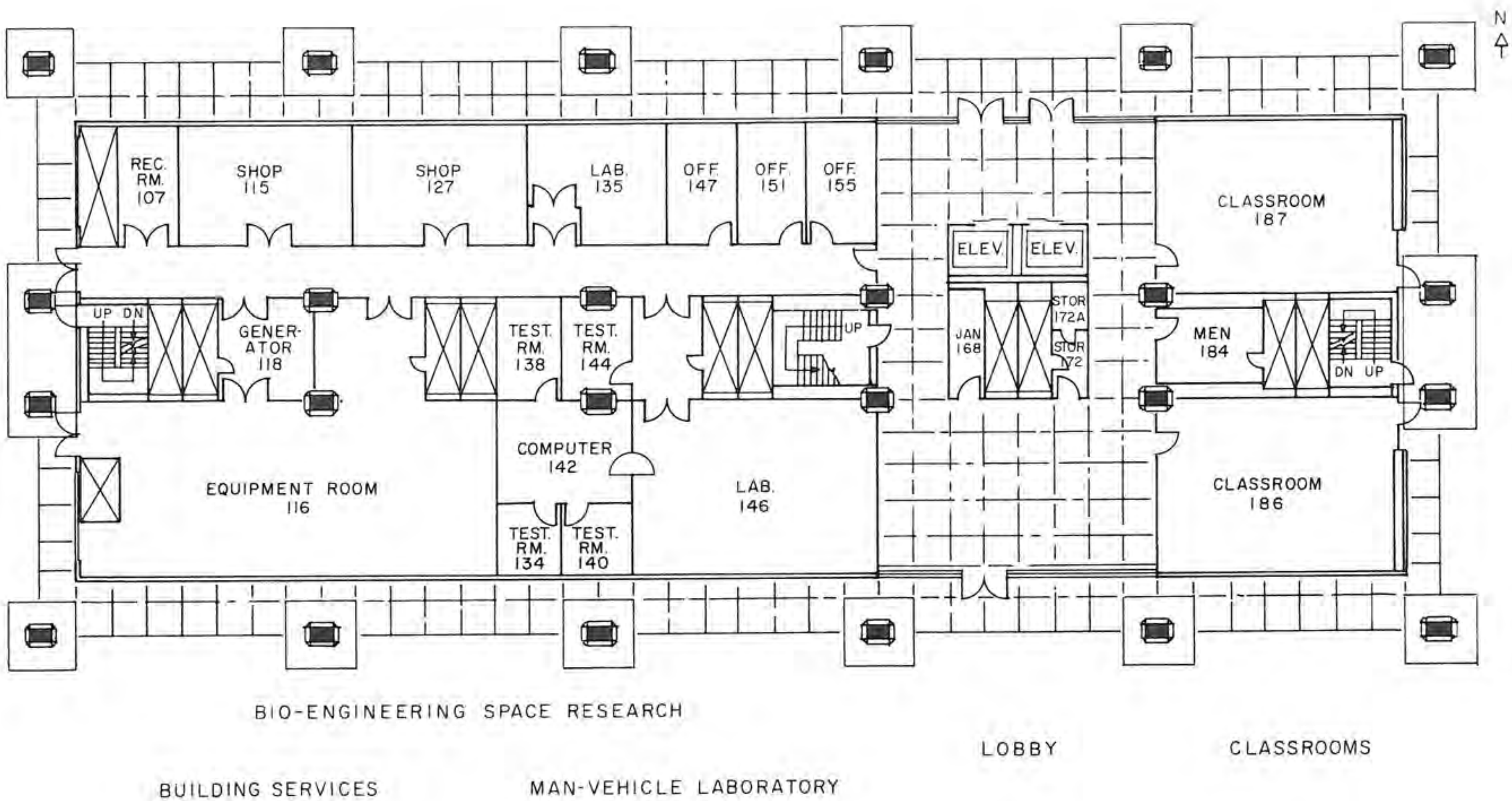
AEROELASTIC AND STRUCTURES RESEARCH LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A CENTER FOR SPACE RESEARCH

BASEMENT

ARCHITECTS SKIDMORE, OWINGS AND MERRILL
SPONSOR NATIONAL AERONAUTICS AND SPACE ADMINISTRATION NGF 22-009-021

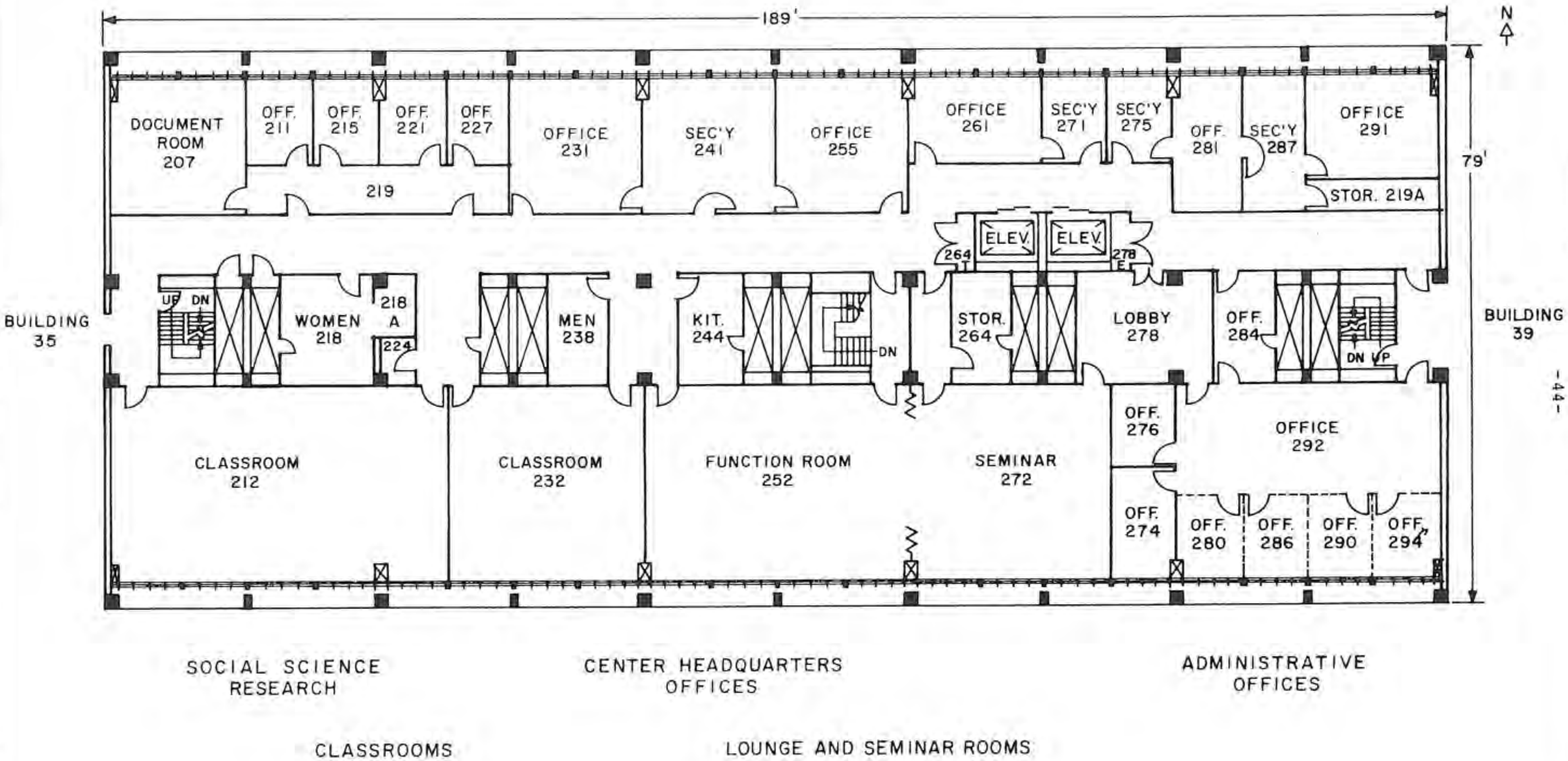


MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A CENTER FOR SPACE RESEARCH

FIRST FLOOR

ARCHITECTS	SKIDMORE, OWINGS AND MERRILL
SPONSOR	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION NGF 22-009-021



MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A CENTER FOR SPACE RESEARCH

SECOND FLOOR

ARCHITECTS	SKIDMORE, OWINGS AND MERRILL
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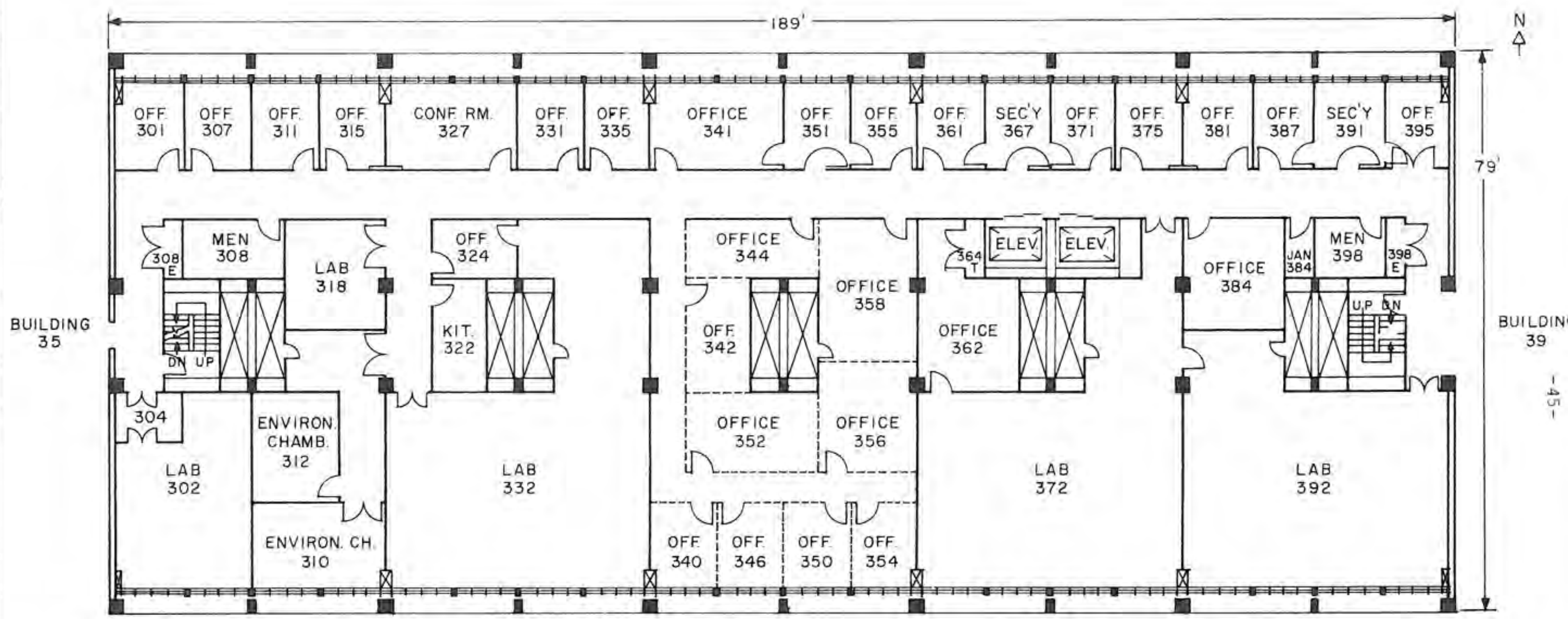
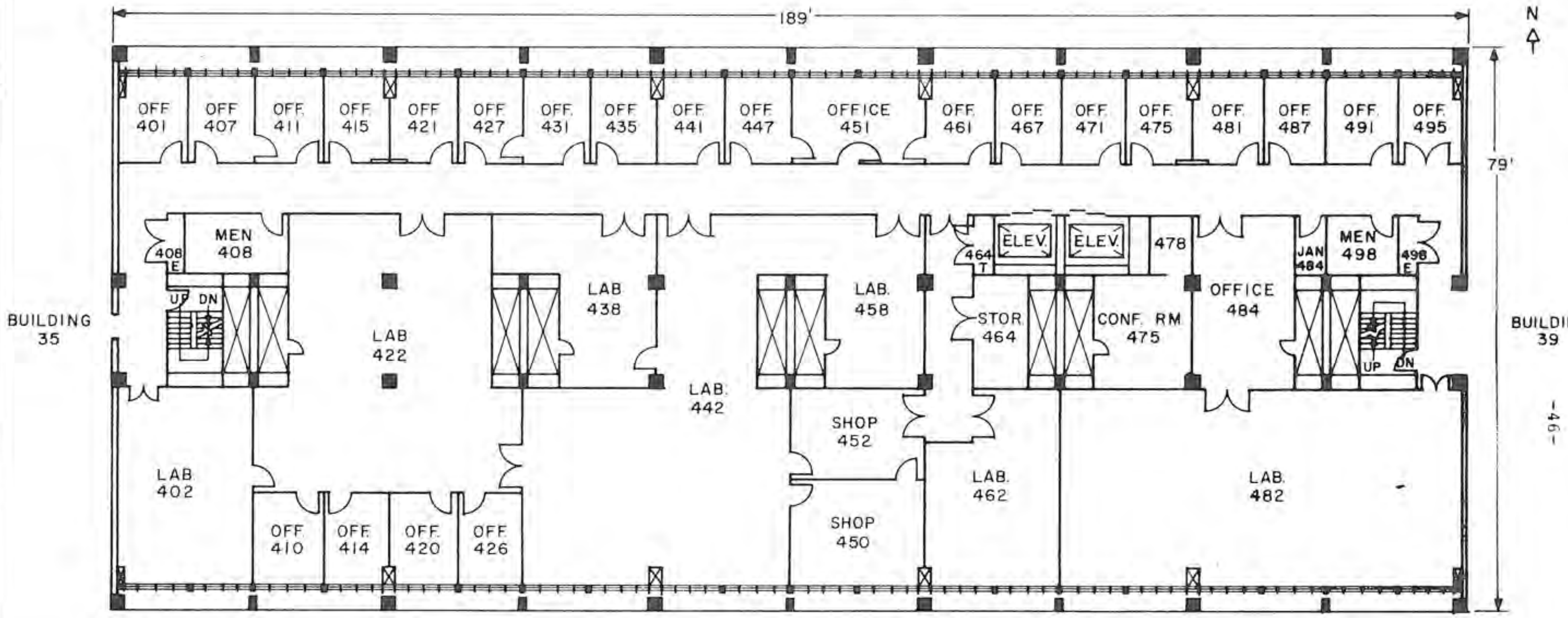


NEUTROENDOCRINE RHYTHMS RESEARCH | PREBIOTIC SYNTHESIS OF POLYNUCLEOTIDES | NAVIGATION OF SPACE VEHICLES | SPACE PROPULSION AND SPACE POWER GENERATION

LIFE SCIENCE RESEARCH | MEASUREMENT SYSTEMS LABORATORY | SPACE PROPULSION LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
A CENTER FOR SPACE RESEARCH
THIRD FLOOR

ARCHITECTS SKIDMORE, OWINGS AND MERRILL
SPONSOR NATIONAL AERONAUTICS AND SPACE ADMINISTRATION NGF 22-009-021



SPACE ELECTRONICS RESEARCH

ELECTRONIC SYSTEMS LABORATORY

RARIFIED GAS-SOLID SURFACE INTERACTION

FLUID DYNAMICS LABORATORY

PLANETARY ATMOSPHERES RESEARCH

PLANETARY SCIENCES LABORATORY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A CENTER FOR SPACE RESEARCH

FOURTH FLOOR

ARCHITECTS	SKIDMORE, OWINGS AND MERRILL
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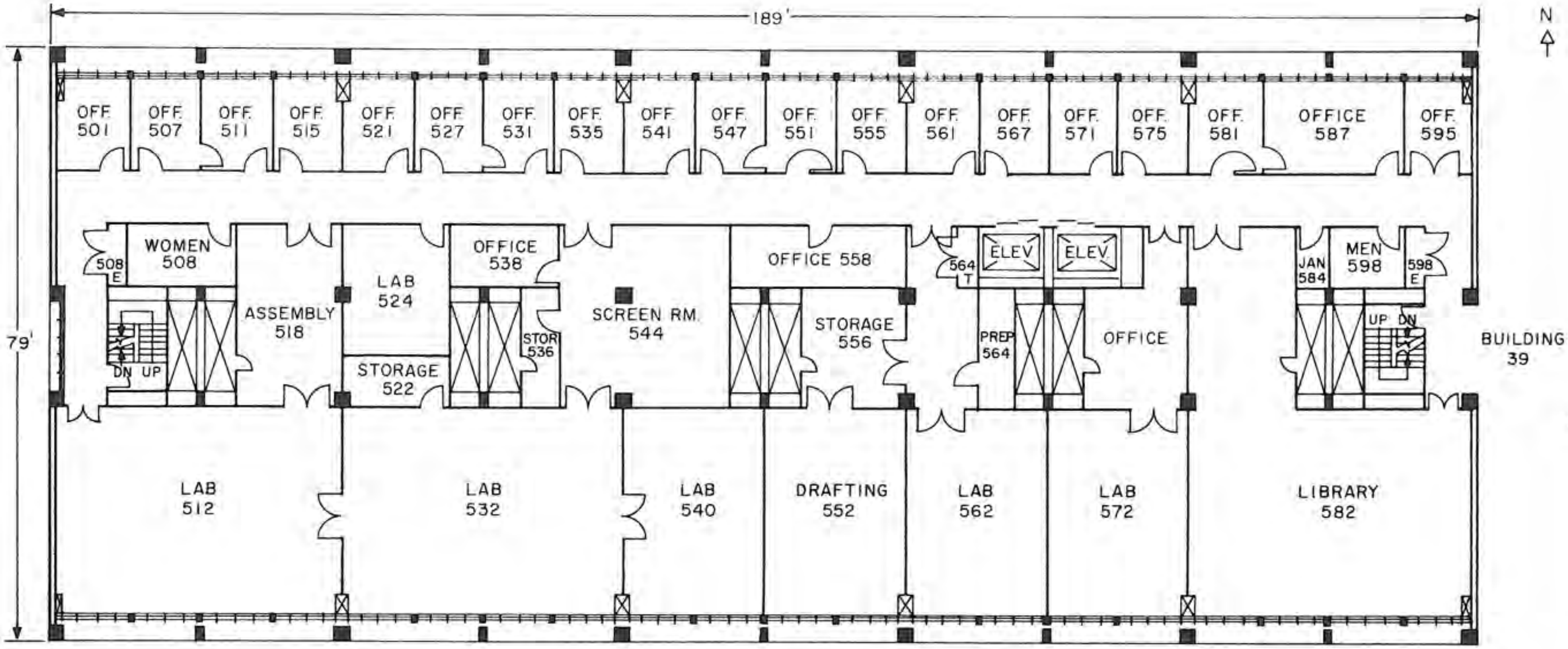


X-RAY AND GAMMA RAY ASTRONOMY

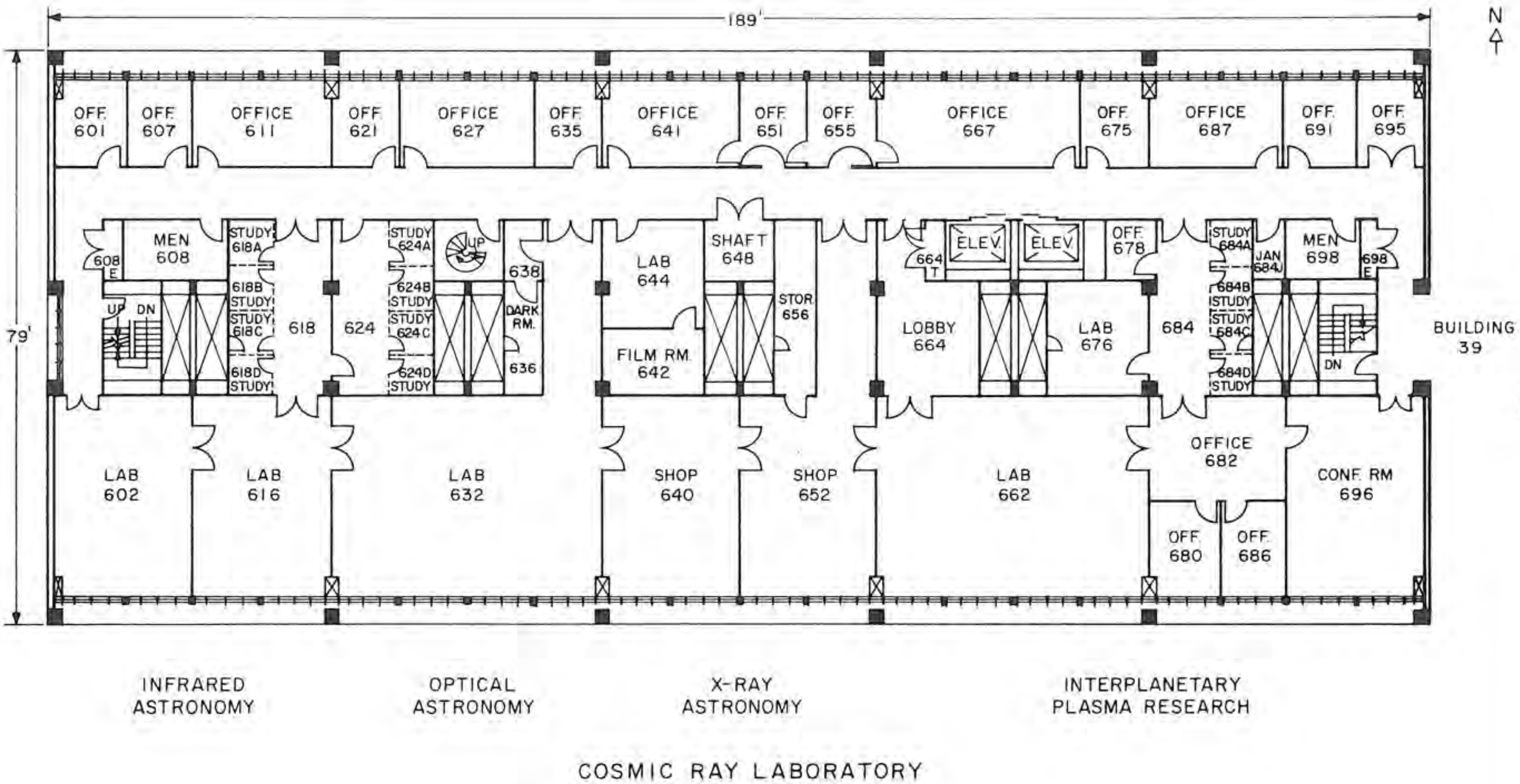
COSMIC RAY LABORATORY

SPACE SCIENCES
READING ROOM

LIBRARY

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
A CENTER FOR SPACE RESEARCH
FIFTH FLOOR

ARCHITECTS SKIDMORE, OWINGS AND MERRILL
SPONSOR NATIONAL AERONAUTICS AND SPACE ADMINISTRATION NGF 22-009-021

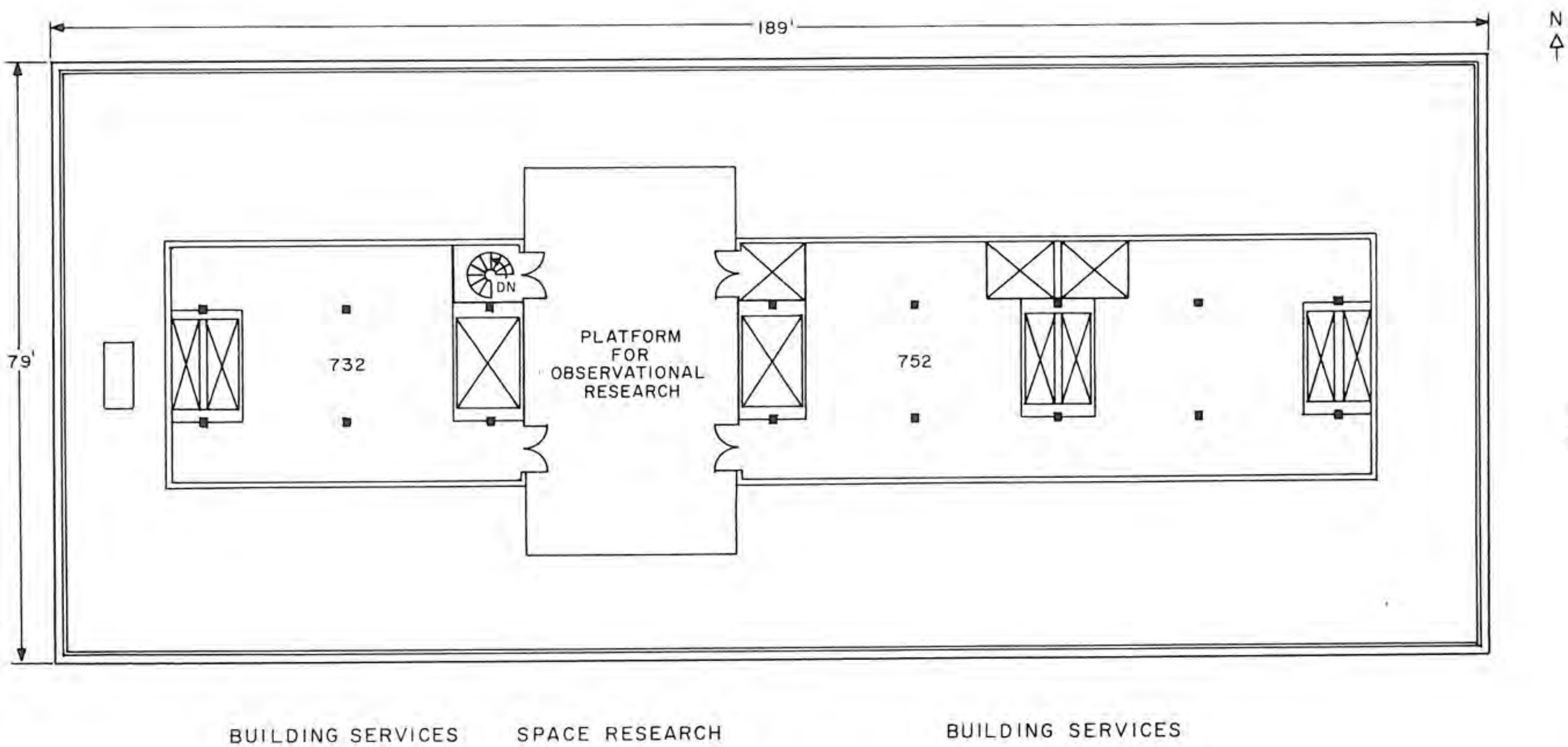


MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A CENTER FOR SPACE RESEARCH

SIXTH FLOOR

ARCHITECTS	SKIDMORE, OWINGS AND MERRILL
SPONSOR	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION NGF 22-009-021



MASSACHUSETTS INSTITUTE OF TECHNOLOGY

A CENTER FOR SPACE RESEARCH

ROOF LEVEL

ARCHITECTS SKIDMORE, OWINGS AND MERRILL
SPONSOR NATIONAL AERONAUTICS AND SPACE ADMINISTRATION NGF 22-009-021

APPENDIX

The following talks and addresses were given at the dedication ceremonies for the new Center for Space Research building at the Massachusetts Institute of Technology, Cambridge, Massachusetts, on April 25, 1968.

Tape transcriptions were made at the time given and thus much of the original material represented unprepared text. Editing of these taped materials was accomplished later by the author of this report, with review and further editing by the respective speakers.

Opening Remarks: DR. JEROME B. WIESNER

The new Center for Space Research at M.I.T. is a focal point for the types of research activities in engineering, biology and the physical and social sciences which will help us obtain a better understanding of the universe, using the various appurtenances of modern space technology such as space vehicles and space platforms.

It is hard for us to realize that this great and burgeoning field of activity has been accessible to us only within the last decade, dating from the first Sputnik flight in 1957. From the start there was the possibility that the space program would be pressed singlemindedly in a direction of quick and glamorous achievements to the neglect of continuing attention to the underlying basic scientific and engineering disciplines essential to long range success. Through the vision and tenacity of NASA leaders, and in particular of James Webb, the battles were fought and won in government circles to maintain a balanced program with a soundly based approach, an approach which NASA has furthered through the creation of a university program which has provided stimulation and assistance to space research activities on many American campuses.

The partnership between M.I.T. and NASA which is being celebrated today with the dedication of this Center reflects a genuine consonance of goals--that space research should be carried out in such a way as not only to meet immediate objectives within the space program, but in such a way that the benefits of this research can also be applied to the social, business and economic structure of the nation. This thought appears explicitly in the memorandum of understanding* between NASA and M.I.T., and I can think of no better way of characterizing our joint effort than to quote or paraphrase other portions of this memorandum: It is the policy of NASA to support or create research environments "characterized by a multidisciplinary effort which draws upon creative minds from various branches of the sciences, technology, commerce, and the arts." Such multidisciplinary efforts are characteristic of the modern university and of M.I.T. in particular. "The successes which American space scientists and engineers have achieved will, in the long run, be regarded as only the pioneer efforts of an ever-expanding space age. Believing that the universities must both reflect and lead the intellectual and cultural life of a society, M.I.T. is determined that its participation in the intellectual adventures offered by the space program shall be an active and growing one and shall constitute a vital part of the well-rounded opportunities for intellectual achievement and technical training that the Institute offers."

* Memorandum of Understanding Between NASA and M.I.T. Concerning Research Facilities Grant NsG(F)-8). Undated. Signed in May, 1963 by Julius A. Stratton and James E. Webb.

J. B. Wiesner
April 25, 1968

Introduction: PROFESSOR JOHN V. HARRINGTON

Thank you, Dr. Wiesner.

I think it would be in order for me to provide just a little background on the genesis of the research program of the Center for Space Research, excerpts from which will be presented by the speakers who follow. The research activities of the Center, under the terms of its charter, can range over topics and disciplines which are quite broad and indeed consistent with the breadth of the national space program itself. The program of the Center by no means includes all of the space research done at the Institute. It does include a large fraction of that not in the large Institute laboratories which is directed toward the education of graduate students. Those of you who have had an opportunity to read the program brochure*will find listed the members of the Center's Technical and Policy Advisory Committees, and you will note that they represent almost every school or department at the Institute. Also in the brochure you will note the large number of researchers already housed within the new building which we dedicate today. The large number of topics and the spectrum they cover clearly made it impossible to do justice to all of the research, of which we are so justly proud, that is properly included within the Center's program. However, we have made some selections which we think are representative and timely for presentation to you this morning.

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* Reprinted on pages 27-37 of this report.

You will hear in the first two talks this morning of some fundamental work done in orbital mechanics as applied to the control and guidance of space vehicles, and a survey of the work in astrophysics in which Center researchers are involved. Following a coffee break and a few words of greeting from the Governor, two additional talks dealing with some exciting new results in the scientific exploration of space for which researchers in the Center are responsible will be given. The morning's presentations will continue with a discussion of the role that the social sciences and management are playing in our program, and conclude with a description of some very fundamental and promising research on the nutritional requirements for manned space flight.

There is much, however, which the brevity of this morning's proceedings requires us to omit. There is a significant effort in space propulsion and power, important work in gas dynamics and plasmas fundamental to the broad interests of the national space program. There is some exciting research on man-vehicle interactions and a host of activities included in the Center's Laboratory for Space Experiments. This latter laboratory represents an important new facility in the Center and is designed to make it possible for faculty and graduate student researchers to play a greater role in making measurements in space and making their work more realistic and, we hope, more stimulating. This laboratory has constructed x-ray telescopes, gamma-ray telescopes, and plasma probes which have flown successfully on many NASA scientific satellites, and sounding rockets. It is well on the way to building its own satellite called Sunblazer, designed to probe the extended solar corona. So, while there is much you will learn about our research program this morning, there is much you will not hear about. We hope that many of you will come again and perhaps have a later opportunity to learn more of these projects which we must omit this morning.

Finally, let me again remind you that the roots of space research at the Institute run deep and stem from the larger laboratories such as the Lincoln Laboratory and the Instrumentation Laboratory off the campus, and such interdisciplinary laboratories as the Laboratory for Nuclear Science and the Research Laboratory for Electronics, and the various departmental laboratories on the campus. The work about which you will hear owes something in some way to each of these and this we all are pleased to acknowledge.

J. V. Harrington
April 25, 1968

PROFESSOR HERBERT S. BRIDGE

One of the most active programs in space research here at M.I.T. has been a continuing series of experiments designed to measure directly the properties of the solar corona at large distances from the sun. Today we know a great deal about the properties of this extended corona or, as it is more popularly known, the solar wind, and practically all of this knowledge has been obtained during the past eight or ten years by means of direct measurements in space carried out by satellite-borne experiments.

In preparing this talk I looked at a recent review article on the properties of the solar wind. In this review is an opening statement which I will quote. It says: "The status of our knowledge of the interplanetary plasma (the solar wind) can be regarded as being highly satisfactory from both the theoretical and observational points of view. That is, despite the rapid improvement of observational techniques and the large amount of data which has been accumulated, nothing has been found which is especially surprising or contradictory to theoretical predictions in any serious way." Now looking back some ten years I think that statement is a measure of how blasé we have become in accepting the scientific results of the space program; we all of us tend to forget the enormous changes in our ideas and scientific knowledge which have resulted from satellite experiments carried out during the last decade.

I think that today, when we are discussing some of the scientific advances which have resulted from the space program, it is particularly appropriate to recall what people thought about the extended solar corona just ten years ago before direct observations and measurements were possible, and then to summarize our current ideas on the subject. About ten years ago it was generally believed that the interplanetary region between the sun and the earth was essentially empty of material, and it was also generally thought that the sun possessed a dipole magnetic field which occupied the space around it out to regions beyond the earth. Now, this picture is somewhat oversimplified in that by 1958 there was a growing body of experimental and theoretical evidence which cast doubt on this simple picture. The experimental evidence, however, was all of an indirect nature and, while suggestive, was far from conclusive. As a result, several conflicting and contradictory theories were advanced to account for the inconclusive observations.

Just at this time direct measurements by means of satellite-borne experiments became possible, and this opportunity was exploited quickly by several groups of experimenters. As a result of four early satellite measurements carried out between 1959 and 1963, the existence of what we now call the solar wind, or the interplanetary plasma, became firmly established and its major properties were measured in a quantitative way.

H. S. Bridge

In every respect these measured properties correspond to a theoretical model proposed by Eugene Parker in 1958. In this model Parker assumed that the corona of the sun could be treated as an ideal gas and, to investigate the expansion of the gas, he applied the usual hydrodynamic equations of motion. The solutions he obtained were identical in form to the equations which describe the flow of gas through the nozzle of a rocket, and they predicted that the corona of the sun should expand radially outward from the sun at a supersonic velocity. More precisely, Parker was able to calculate the expansion velocity of the corona as a function of radial distance from the sun, and he predicted that in the vicinity of the earth the plasma flow would be directly away from the sun with a velocity of several hundred kilometers per second. He also predicted one other very important result which I shall try to explain with the aid of the drawing in Figure 1. At the top of the figure we see a view in the equatorial plane of the sun looking down on the north pole. In this view, the sun rotates in a counter-clockwise sense. Imagine that the sun emits particles continuously from a small region on the surface and that these particles move radially outward as shown by the arrows. Then the position of the particle stream at a given instant of time is shown by the heavy solid curve. For the case in which the speed of the particles is constant, the locus of the particle stream forms an Archimedes spiral. Note particularly that the particles do not move along the heavy curve; they move directly outward from the sun and the curve merely defines the location in space of particles which have come from a given point on the sun.

Now I have to digress a moment to mention something which is familiar to plasma physicists but is perhaps not generally so well known. In a highly conducting plasma, a magnetic field behaves as if it were frozen into the material. Put in another way, there can be no bulk motion of plasma particles perpendicular to the magnetic lines of force. Thus, if we imagine a loop of magnetic field rooted in the sun on each side of the emitting region, the loop will be pulled out by the plasma stream so that the lines of magnetic force coincide with the position of the particle stream. Thus the magnetic field lines are curved and correspond to the Archimedes spiral shown in the slide. But, of course, this picture for a single emission region holds equally well for a uniform expansion of the corona in which all of the plasma moves radially outward with a constant velocity from all parts of the surface. Thus in the equatorial plane of the sun, Parker's model predicts the situation shown at the bottom of Figure 1 where the particle motion is shown by the arrows and the spirals indicate the structure of the magnetic field of the sun.

In summary, then, according to Parker's model, a satellite-borne experiment near the earth should observe a plasma wind coming from the sun indicated by the arrows. This solar plasma is composed mostly of protons and electrons with speeds between 200 and 1000 km/sec depending on the temperature of the corona. (The corresponding proton energies which one would measure in an experiment lie between 200 and 5000 eV.) In addition, Parker predicted that the emission of plasma would be a continuous or nearly continuous phenomenon and that the plasma would contain an embedded spiral magnetic field. It is difficult at this time to recall the skepticism with which this theory was greeted by most of the scientific community; however, it has been confirmed in every detail. Let me recall in terms of the experiments how the theoretical predictions were verified.

In 1959 Gringauz and his co-workers made the first direct observations of the interplanetary plasma using the Soviet spacecraft Lunik 2 and Lunik 3. The experimenters reported that they detected a directional positive ion flux with ion energies above 20 eV. Although these experiments were consistent with the theoretical predictions, they were inconclusive for several reasons. First of all, the spacecraft was not stabilized and so its orientation was not known. Thus, although the ion flux was certainly directional, there was no information to show that it came from the sun. Secondly, photoelectric effects were known to be large for the instrument used and thus the results were open to some question. Thirdly, the measurements covered only a short period of time. The Russian experiments were followed in 1961 by an experiment by the M.I.T. group on Explorer 10, and in 1962 by an experiment on Mariner 2 carried out by Snyder and Neugebauer at JPL. The Explorer 10 experiment gave the first clear evidence for a supersonic flow of plasma coming from the sun, but the measurements lasted only about 20 hours and thus were not completely conclusive. The Mariner 2 experiments provided nearly continuous measurements of solar wind parameters over a period of nearly five months and showed that the solar wind was a permanent feature of interplanetary space. The final piece of evidence was provided by definitive measurements of the interplanetary magnetic field carried out by Ness at the Goddard Space Flight Center on the IMP-1 satellite in 1963. In a classic series of measurements Ness showed that the magnetic field carried by the solar wind had the general spiral character predicted by Parker. So, only as recently as 1963 has the solar wind been an established feature of the solar system.

Since these exploratory measurements were made, a great deal of additional work has been carried out by a large number of experimenters. It is impossible even to summarize the results in the time available this morning. Instead I want to discuss briefly some of the problems which are being studied here at M.I.T. and give some selected experimental results. Perhaps the most obvious problem is what are the average properties of the solar wind and how do these properties change in response to short term and long term solar activity. Figure 2 shows a commonly used index of solar activity, the sun spot number, plotted as a function of time. Also shown in Figure 2 are the times during which the various satellite experiments were carried out. Note that the measurements on IMP-1 (Explorer 18) were taken close to the time of minimum solar activity; the Mariner 2 experiment was made at a time when the sun was somewhat more active and the Mariner 5 experiment was carried out near the time of maximum solar activity.

Figure 3 shows histograms of the plasma velocities and densities measured in the IMP-1 and in the Mariner 5 experiments. On IMP-1 the average velocity was 360 km/sec and the average positive ion density was 10 particles cm^3. For Mariner 5 the corresponding values were a velocity of 400 km/sec and a density of 7 particles/cm^3. Thus the average properties of the solar plasma do not change markedly during the solar cycle.

Another aspect of the solar wind which I should like to mention is its interaction with the earth. As I said previously, the solar plasma is an excellent electrical conductor. For this reason the solar wind cannot penetrate directly into the magnetic field of the earth and is forced to flow around it. On the sunward side the solar plasma compresses the geomagnetic field until the dynamic pressure of the plasma is balanced by the pressure of the compressed geomagnetic field. This occurs at about 10 earth radii, and for this reason it was expected that a cavity in the solar wind of about 20 earth radii in diameter would be produced. However, the velocity of the wind is about 400 km/sec whereas the speed with which a signal can propagate in the plasma is only about 50 km/sec. For this reason, the oncoming plasma cannot "know" that the earth is there and, on general grounds, one would expect that a bow shock wave would form ahead of the earth. Definitive proof that these ideas were correct was obtained in 1963 from plasma and magnetic field observations carried out on IMP-1 by M.I.T. and by the Goddard Space Flight Center.

Since that time there has been a great deal of experimental and theoretical work on the interaction of the solar wind with the geomagnetic field, and Figure 4 shows a schematic summary of these results which was recently given by Ness. Close to the earth is a region called the magnetosphere which contains the geomagnetic field and into which the solar wind cannot penetrate. Beyond the magnetosphere is a so-called transition region (magnetosheath) which separates the geomagnetic cavity from the undisturbed wind; further up stream is a shock wave which separates the undisturbed wind from the hot plasma in the transition region. Now if we follow the plasma flow along a streamline which passes near the subsolar point, that is along the earth-sun line, we find that the plasma slows down as it passes through the shock and becomes very hot as the kinetic energy of the ordered supersonic flow is converted to random motion. Behind the shock the hot plasma expands and is deflected to flow around the magnetosphere. As it does so, the gas expands, the velocity increases, and at some point downstream the flow again becomes supersonic. At the magnetopause there is some sort of interaction between the plasma flowing in the magnetosheath and the magnetic field of the magnetosphere. As a consequence of this viscous force, the magnetic field of the earth is pulled out into a long tail which extends at least several hundred earth radii in the downstream direction.

I should point out that the properties of the solar wind itself are better understood at this time than many of the geophysical effects which the wind produces. For example, although considerable progress has been made, no satisfactory theory which describes the formation of the bow shock has been developed; also while many other geophysical phenomena, for example the aurora and the radiation belts, are most certainly closely related to the interaction of the wind and the earth's field, a detailed explanation is lacking. To a large extent this lack of understanding reflects our lack of theoretical knowledge concerning completely ionized collisionless plasma.

As a final example of research on the interplanetary plasma, I should like to mention some of the results obtained from Explorer 35. Explorer 35 was launched last July and was successfully injected into orbit around the moon. It represents the first attempt to study and monitor the particles and fields environment of the moon using a long-lived, closely coordinated set of experiments. One of the main objectives was to study the behavior of the solar wind near the moon, not only to study the interaction itself but also to try to find out something about the moon. Now if the moon had an intrinsic magnetic field comparable to that of the earth, the behavior of the plasma could be predicted by appropriately scaling the effects found at the earth (see Figure 4). In general, the presence of such an intrinsic field will lead to the formation of a lunar magnetosphere and to a bow shock upstream from the moon. When these experiments for Explorer 35 were being designed, it was already known that the lunar magnetic field was weak compared to the field of the earth. Nevertheless it seemed probable that characteristic effects caused by a weak lunar field might still be detectable in the plasma flow close to the moon. Even if the moon had no magnetic field of its own, it could, under reasonable assumptions, behave as though it did. This comes about in the following way. If the moon is a good conductor, the magnetic field carried in by the solar plasma cannot diffuse through the moon as rapidly as it is convected in by the wind, and as a result the field strength on the windward side increases, thereby increasing the diffusion rate until a steady state is achieved. Thus even if the intrinsic field of the moon is zero, the moon could conceivably acquire a field from the plasma.

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The experiments carried on Explorer 35 were designed with these possibilities in mind.

Explorer 35 was injected into lunar orbit on July 22, 1967. Its closest approach to the lunar surface is about 0.4 lunar radii and at its greatest distance the satellite is about 4.4 lunar radii from the lunar surface. The orbital period is just under half a day. At the time Explorer 35 was placed in lunar orbit, the moon was passing through the geomagnetic tail of the earth and, to obtain measurements in the solar wind, it was necessary to wait for a little over a week until July 27th when we were certain that the moon and satellite were in the undisturbed solar wind and not subject to any influence of the earth.

Figure 5 shows a series of plasma measurements taken for a period of roughly 1.5 hours on July 27th during which time the spacecraft passed through the lunar shadow. In the figure, successive blocks of plasma data are plotted with time running horizontally; each line represents a 4.3 second data record which is repeated every 164 seconds. The plasma intensity is plotted vertically. Now how do we interpret these data? First of all, recall that the satellite was spin stabilized so that as the spacecraft revolves the plasma detector looks alternately into and away from the plasma stream. In Figure 5 we notice first of all that at the top and bottom of the figure the plasma signals show a large "roll modulation;" that is, they are very strong when the plasma detector points in a particular direction and very weak when it points in other directions. We can tell the direction the plasma detector points relative to the sun because there is a photocell mounted on the satellite which gives a pulse each time it passes the sun. From this "optical aspect sensor" we find that the maxima in the plasma signals indeed occur almost exactly at the time when the detector points at the sun. This, of course, is just what we expect for the undisturbed solar wind. Moreover, the width of the signals depends on the temperature of the plasma: for a cold plasma the peaks are narrow; for a hot plasma they are wide. Again, the width of the signals shows that we are dealing with the undisturbed solar wind and not with a very hot plasma which has passed through a shock.

The central portion of the figure represents the time when the satellite passes behind the moon. As it does so, the plasma signals first decrease and then disappear completely. Then, as the satellite emerges from the lunar shadow, the sequence of events is repeated: the signals reappear first with reduced size and then with full amplitude.

Now how do we interpret these data? For the case of the earth four plasma parameters change drastically across the bow shock. These are the direction of flow, the temperature, the speed and the density. During four months of plasma observations with Explorer 35, no changes in these parameters have been observed near the moon which could be interpreted as a shock.

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What can we say about the absence of a shock? In general, a shock forms because ions or molecules are reflected at the boundary of some obstacle in the flow. For the earth, this obstacle is the magnetic field, and we conclude that, since the moon has no shock, it has no appreciable magnetic field, either instrinsic or accreted from the solar wind. In this case one might expect that the solar wind would strike the surface of the moon directly and be completely adsorbed. Thus, no charged particles are reflected and no shock is formed. Indeed as far as we can tell, this seems to be the case.

Because the plasma which strikes the sunward side of the moon is adsorbed, a plasma shadow or void exists downstream from the moon. If the solar wind is very cold, all of the ions move in the direction of the wind velocity; if it is hot, the ions still move mostly in the direction of flow but also at right angles to it. Because of this transverse motion, the solar wind ions tend to fill the cavity behind the moon.

A schematic representation of the results is shown in Figure 6. Here the dotted lines labeled (1) indicate the optical shadows; the dashed-dotted lines labeled (2) show the plasma shadow expected for a cold solar wind; the solid lines at (3) show the shadow for a hot wind with a temperature typical of that usually observed in the undisturbed solar plasma. It is clear from the figure that the plasma signals fall to zero at a point well inside the geometrical shadow and that a conical cavity which extends a few lunar radii downstream is formed behind the moon.

I have as yet not mentioned the magnetic field measurements carried out on the same satellite independently by Sonnet at Ames and by Ness at GSFC, and since I am primarily concerned with the plasma measurements, I do not intend to dwell on them. I shall only say that the magnetic measurements lead to the same conclusions and that from them it may be possible to obtain additional information about the interior of the moon.

Now before closing I should like to state our conclusions about the plasma flow around Venus as contrasted with the results for the earth and the moon.

The interpretation is based on magnetic field and plasma measurements carried out on Mariner 5 by the experimenters from the JPL, CIT, UCLA and M.I.T. Our results indicate that the solar wind does not interact with Venus to form a shock identical to that at the earth but that the situation is somewhat similar. Recall that the bow shock of the earth is located about 15 earth radii upstream from the planet. In the case of Venus, shown schematically in Figure 7, the shock is very close to the surface of the planet and is probably formed because of an interaction between the solar wind and the ionosphere of Venus. So far, then, we have examined the interaction of the solar wind with the earth, the moon, and with Venus. Each case is different and, while the results are understood in a qualitative way, much remains to be done theoretically and experimentally.

In conclusion, I should like to point out that this program of research which I have been discussing has been going on here for some eight years. It has involved the efforts of a large number of people at M.I.T., at NASA and in industry. In this short review, it is impossible for me to give proper recognition to the individuals who have contributed to the program. Personally I should like to express my thanks to my associates here at M.I.T. and to convey our collective appreciation to our colleagues at NASA for their support and encouragement.

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April 25, 1968

PROFESSOR WILLIAM L. KRAUSHAAR

The search for high energy cosmic gamma rays with space vehicles and balloon-borne instruments has had a rocky history. To date there has been a one-to-one correspondence between discovery and undiscovery. And there has been an unusual amount of enthusiasm among the undiscoverers. This is the background George Clark, Gordon Garmire, Paul Higbie and I had in mind as we decided what I should say here today about the results of the gamma ray experiment we have been carrying out on the third Orbiting Solar Observatory.

Gamma rays are high energy quanta of the electromagnetic field. Since they are electrically neutral, they travel through space in straight lines, undeflected by the galactic magnetic field. However, they are rapidly absorbed by the earth's atmosphere so that their observation is a task for space astronomy.

Gamma rays are characteristic indicators of the most energetic phenomena that occur in the astronomical universe. We know from laboratory experiments that gamma rays are created in collisions between energetic charged particles and matter and, therefore, that astronomical observations of cosmic gamma rays will tell us about the regions of space in which these important ingredients exist. It is appropriate, and certainly not accidental, that the rich new field of high energy space astronomy has been opened by groups closely associated with M.I.T., and in particular, with Professor Bruno Rossi who has been in the forefront of cosmic ray studies since the early 1930's.

The observational results that I shall describe were obtained with an instrument carried into orbit on March 8, 1967, on the third Orbiting Solar Observatory. The instrument has been working well ever since.

Since gamma rays are electrically neutral, the only way we can detect them is to detect the charged particles they produce. In the OSO-3 instrument this is done with an assembly of scintillation and Cerenkov detectors enclosed within a box of plastic scintillator. The box is itself a detector of charged particles and whenever it registers the passage of a charged particle the apparatus is temporarily turned off. Thus only electrically neutral particles which produce the characteristic gamma ray reaction in the inner detector system are recorded.

The electronic portion of the detector instrument was designed and constructed at the Lincoln Laboratories of M.I.T. Two of the people who were largely responsible for that effort are now at the M.I.T. Center for Space Research--Richard Baker and Robert Rasche.

In orbit the device detects gamma ray events at the rate of about one per day from the open sky. During this time about 10 million charged cosmic ray particles pass through the instrument. With a detection rate which is this small, it is very important that we monitor the functioning of the device to insure that it is behaving properly. To do this we record a variety of "housekeeping" data, which are telemetered continuously to provide a check of the instrument's performance. These data are displayed graphically for visual inspection. Among the housekeeping data are the individual counting rates of the various elements in the detector system. These rates show the expected wide variations due to the variation of the charged cosmic ray intensity with geomagnetic latitude. The effects of periodic excursions into the earth's Van Allen radiation belts are also evident and events accumulated during these periods of time are excluded from the gamma ray data. Whenever a gamma ray event is detected, the routine transmission of the housekeeping data is interrupted and detailed information about the event is transmitted.

The gamma ray detector is mounted so that it looks out along a radius of the wheel of the OSO spacecraft. It therefore scans the sky and earth each time it rotates. Ordinary charged cosmic rays generate many gamma rays when they hit the earth's atmosphere. As a result the rate of gamma ray event is high when the instrument is pointed toward the earth and reaches a maximum when it points toward the horizon. In contrast, the rate of gamma ray events from the sky is very low. We are confident, however, that the "sky events" we detect are due primarily to genuine cosmic gamma rays.

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One critical test of our contention that the tiny sky flux we have detected is, in fact, a true cosmic gamma ray flux and is not just an instrumental effect is whether the rate of sky events varies with the geomagnetic latitude of the satellite as it moves around the earth. The cosmic ray background goes up and down with geomagnetic latitude. If the detected gamma rays are of cosmic origin, there ought to be no dependence whatever on the geomagnetic latitude. In fact, no such dependence is evident in the rate of sky events.

Our galaxy is a large flat disk, the Milky Way. This disk contains stars, gas and cosmic rays. Since the interactions of cosmic rays and gas produce gamma rays, we expect the intensity of gamma rays to be greatest in directions lying close to the plane of the galaxy. In fact, the observed rate is markedly greater in the galactic plane than it is towards the galactic poles. We regard this as our strongest evidence that we are observing cosmic gamma rays.

Of great interest also is the variation of the gamma ray intensity with galactic longitude, the angle measured in the plane of the Milky Way and away from the center. This variation may indicate how galactic gas and cosmic rays are distributed. In fact, the data show a strong concentration toward the galactic center region.

The data I have described were accummulated over only 23 weeks. Our detector and OSO-3 are still working well and we

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trust data yet to be recorded will strengthen the interpretation I have given here today.

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PROFESSOR WINSTON R. MARKEY

One of the laboratories in the Space Center, the Experimental Astronomy Laboratory, has been concerned with instrumentation for physical measurements.

The basic discipline of the students and staff members in the Experimental Astronomy Laboratory is the design of inertial navigation systems. Three areas of research have emerged from this basic discipline. They are: first, methods of inertial and optical instrumentation; second, studies of gravitational and electromagnetic fields; and third, the design of both terrestrial and deep space navigation systems.

A principal motivation has been to apply the methods of automatic geometric measurements to explorations in the terrestrial and extraterrestrial sciences. These methods have been developed by the M.I.T. Instrumentation Laboratory largely through DOD and NASA support. In our current activities we have a mixture of scientific research and engineering development which, to a significant extent, is practiced by graduate students working with members of the faculty and research staff.

Over a number of years we have studied the instrumentation of balloon-borne telescope stabilization systems. One of our original problems was to determine the parameters for stabilization systems that could be used for both manned and unmanned experiments. The two sources of disturbance were recognized to be stellar scintillation and biological noise (in the use of manned systems). In cooperation with the Smithsonian Astrophysical Observatory we conducted a series of flight experiments designed to measure the effect of these sources of disturbance on the stabilization of a variety of optical instruments. Early balloon flights were designed to measure stellar scintillation as a function of altitude up to 60,000 feet. This system was used to measure the scintillation spectra of Polaris and Delta Ursa Minoris.

Subsequently we conducted a manned flight at Hollman Air Force Base using a twelve-inch Cassegrain telescope mounted in a stabilization system on top of a two-man gondola. The stabilization and orientation control system allowed the observer to position the telescope, through an optical link, on subjects of interest. After acquisition, an automatic tracking and stabilization system controlled the orientation of the telescope. The components in the system were similar to those used in aircraft navigation and missile guidance systems. The results of this experiment showed that a stabilization accuracy of a second of arc or less in a manned system is possible with this type of equipment.

During this research we became interested in atmospheric light in connection with the performance of star trackers. Both balloon and rocket experiments were subsequently conducted. I shall discuss first the experiments using optical and electronic instrumentation designed for balloon vehicles. The upper hemisphere was scanned by the lens in the dome at the top of the balloon gondola, and the signal from a photodetector operating in the visible spectrum was recorded on board. The instrument package was mounted in a frangible landing structure. Russell Schweickart, who is one of three astronauts who pursued graduate studies in the laboratory, assisted in the conducting of these experiments.

Data were obtained which compared the measurements at an altitude of 102,000 feet with a theoretical model proposed by Chandrasekhar. The divergence of the experimental data curves at low elevation angles was not surprising since the theoretical model assumed a flat earth. The reason for the divergence of the experimental data curves was not certain, but stray light might have entered the photometer through reflection off the balloon.

The second example of our research concerns the extension of these instrumentation techniques to an aircraft. In cooperation with the Air Force Cambridge Research Laboratories, a group has been engaged in an experimental program of air-borne gravity measurements.

The measurements of the figure of the earth and of its gravitational field are being improved by a variety of techniques. The large scale or global features are now being measured quite accurately by satellite geodesy. However, small scale features, or local variations, cannot be resolved by the satellite observations and gravimetry must be used for this purpose.

Gravity measurements made by an instrument at rest on a firm base are a classical problem, and high resolution instruments for such measurements have been available for several decades. However, much of the surface of the earth is covered by water so that a firm base is not available, and some of the land areas are remote or inaccessible. Thus, measurements on marine vehicles or in an aircraft are necessary.

Adaptations of the land instruments to moving vehicles have been made, but those very characteristics responsible for high accuracy tend to interfere with the measurements when the instruments are in motion. To overcome these difficulties, this group has been applying the equipment and techniques of the inertial guidance field to this geophysical problem.

The gravity meter we are using is an accelerometer from the Titan III space booster guidance system. This instrument is of the pendulous gyro type as designed at the M.I.T. Instrumentation Laboratory. It was produced by the A.C. Electronics Division of the General Motors Corporation.

The basic accelerometer, known as the Type 25 PIGA, was modified to incorporate a thermal control and magnetic shield designed by the Experimental Astronomy Laboratory for use in this project. The instrument uses principally Titan electronics with only minor changes.

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The instrument readout and data recording system were standard commercial equipment.

In order to keep the accelerometer pointed in the vertical direction, a stable platform was needed. This stable platform was assembled from components of a camera stabilization platform and of an inertial platform used in a Doppler-inertial navigation system. These existing platforms had both adequate size and performance for our needs.

The entire system was first installed in a KC-135 jet aircraft. However, this aircraft was reassigned to other purposes not long after the installation, and the equipment was subsequently installed in a C-130 aircraft. A series of successful flights was made during the past winter and spring over gravity ranges in Montana and in the Southwest. The data from these flights are now being analyzed. Indications are that the goal of this research will be realized. Airborne gravity measurements to within a few milligals (a few parts per million), over areas five degrees square, appear to be possible.

In connection with this experimental program, studies of methods of terrestrial navigation are being conducted. Of principal interest here are optimum configurations of hybrid inertial systems and techniques of barometric altimetry. This research has a direct connection with the evolution of avionics systems for SST and VTOL aircraft.

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In addition to these terrestrial studies, we have several graduate students involved in astroguidance studies. Before reviewing this work, however, I should like to mention an experiment which has evolved through earlier research on methods of small displacement detection using a laser.

Recently, through a joint effort between the Experimental Astronomy Laboratory and the Research Laboratory of Electronics, Shaoul Ezekial and Rainer Weiss, of the Physics Department, have observed for the first time a laser-induced transition in a molecular beam. They have demonstrated that a 5145 Å argon laser induces resonance fluorescence in a molecular beam of iodine. The natural width of the iodine resonance line is very narrow, around 50 kHz, and the shifts in the center frequency of this line are very small, if the transition is observed in a molecular beam.

The significance of this experiment lies in the possibility of using this iodine resonance, which is excited by the laser, in the beam, as a primary reference in the feedback stabilization frequency. Preliminary calculations indicate that it may be possible to achieve long term stability and resettability of the laser frequency to a few parts in 10^{13}.

The stabilization scheme using this principle is defined as follows: Light from the laser is passed through a molecular beam of iodine and the induced resonance fluorescence is detected and used in a feedback loop to maintain the laser frequency at the center of the iodine resonance. In actual practice, a Fabry-Perot interferometer is used as a short term reference and the molecular beam signal is used to regulate the resonance frequency of the Fabry-Perot interferometer for long term stability.

A stabilized laser of this type can be applied to research in precision length measurements, such as those required in geophysics and in length standards; in laser communication, and in experimental relativity.

Returning now to the other side of our analytical work, the astroguidance group has a two-fold purpose: first, to make exploratory or pilot investigations to dynamics problems that are of interest to NASA; and second, to provide a suitable environment for graduate students engaged in thesis research.

Because of the limited size of the operation, we do not make exhaustive studies of the problems that confront us. Rather, our objective is to determine the feasibility of a variety of simplifying techniques in solving a problem.

The general areas of our research effort include interplanetary trajectories and guidance, optimal control theory and earth satellite theory.

An early result obtained in the study of interplanetary trajectories was that a significant saving in fuel can be effected in an interplanetary transfer if, on the way from earth to the destination planet, the space vehicle swings by an intermediate planet; for example, a swingby of Venus can be used in a flight from earth to Mars, or vice versa.

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In another study, the dynamics of interplanetary flight was simplified by considering only the effect of the sun on the vehicle. It was then possible to obtain a closed form solution to the perturbed two-body problem involving an elliptical orbit. This work was extended and at the present time closed form solutions exist for all conic sections. As a result it is possible to devise analytically a logic for mid-course guidance correction.

This simplified technique is not so accurate as the elaborate digital techniques that are used, but it is adequate for mission planning purposes and is very much cheaper to implement.

Both these results--the swingby trajectory and the simplified guidance solution--have been studied by investigators at other institutions. We merely wish to point out that this type of research can be carried out effectively yet inexpensively (frequently by students).

The "early" guidance studies were primarily feasibility studies, designed to determine whether and how a mission could be accomplished.

The emphasis in more recent work is on performing a mission "optimally"--i.e., obtaining (through filtering) the best possible estimate of the state of a system and applying the necessary control for the system in the most efficient manner. Thus, we are engaged in research which has as its objective the determination of an optimal strategy when it is known that the available data are noisy and there is uncertainty in the application of the corrective control. The computing requirements for solving practical problems of this nature are so great that full numerical solutions are not usually obtained. We are searching for simpler computer algorithms, based on insight into the fundamental physics of the system, which make such problems tractable.

In addition to the deep space studies, we are involved in earth satellite theory. We are looking into possible satellite experiments which will provide useful data for geodetic and oceanographic purposes. Specific problems being investigated include the location of major oceanic current systems and the use of filtering theory to eliminate undesirable wave effects from radar altimeter readings taken over the oceans.

One part of these studies has evolved into an experiment, and I should like to discuss this experiment as the last example of our research.

During the past two years we have been participating in NASA's Earth Resources Program. Our task has been to examine the usefulness of aerial photographs and the measurement of color patterns by instrumental means as a method of improving the understanding of the processes at work in the ocean, with an eye to the satellite programs that we expect in the future.

In the past we have attempted to measure and understand it from the single point which an oceanographic research ship occupies. Today we have the promise of viewing the sea from a greatly improved vantage point.

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As an example of the methods that we use with today's technology, we look at photographs such as an aerial view of a beach and a pond on Cape Cod. The differences between an eutrophic fresh water pond and the ocean, which may be determined by painstaking work by men on the earth's surface, are readily apparent in these photographs. Close examination of photos such as these by trained observers can tell a great deal about the age and condition of the pond and about the nature of the ocean. The color, the transparency and the general appearance of the water at the seashore may lead to good estimates of the state of the water masses present, the natural and human processes acting nearby and the potential for fisheries and mineral exploitation.

Our techniques of analysis include spectra-photometry, microdensitometry and more qualitative methods of photo interpretation. The research is being done in collaboration with marine biologists and geologists at Harvard College and at the Woods Hole Oceanographic Institute. As equipment, we use a spectra-photometer which was developed for the rocket exploration of light in the atmosphere mentioned earlier as well as a filter wheel which permits scanning the visible spectrum from 4000 Å to 7000 Å in windows 100 Å wide. Eleven of these instruments were flown on a variety of missile boosters during an investigation of light in the upper atmosphere.

Our present work is being done at test sites in the Bahama Islands and in Miami's Biscayne Bay. We have taken aerial views of the Bahamian site from a NASA airplane at altitudes up to 25,000 feet. The islands visible include North and South Cat Cays, and Guy Cay, just north of Miami. These photographs show the geological and biological features of the ocean bottom in the waters surrounding the islands as well as some of the information we require to improve the charts of the region. From the patterns on the photographic images, we can see the distribution of the major biological assemblages on the floor of the sea and from these we may deduce something of the physical nature of the ocean at this point: its temperature and salinity, the range of the tides, and the forces caused by waves and currents. These photographs, and others like it, have been taken as part of an experimental program to determine the information that we shall be able to collect with satellite photographs of the earth.

Additional photographs taken during the flight of the Gemini XII spacecraft show the same area in the Bahamas from an altitude of 120 miles, taken with a small, hand-held camera. Such items as sand bars are visible in these pictures, and closer inspection shows that the islands are also visible. These photographas, as remarkable as they are, may be considered only a foretaste of the kind of material we shall have available to work with in the 1970's when the NASA Earth Resources Survey satellites are launched. One photograph may show a region where little human activity, of a kind detrimental to or disruptive of the natural environment, has occurred, whereas others in adjacent areas may show an area where this is no longer true. When these photographs are examined, the effects of man's unplanned activities become apparent. Whether this disruption of the natural processes is destructive is not definitely known, but the experience to be drawn from the condition of our rivers and lakes should not be overlooked. So far, the only detailed satellite instrument coverage that has been available to us has been of the equatorial and subtropical regions that have lain beneath the paths of the Gemini spacecraft, such as those photographs of the mouth of the Colorado River and the Gulf of California or of Southern India and Ceylon. By the beginning of the next decade, however, all of the temperate zones will have been covered.

By the time those flights are a reality, we hope to have done enough work on the interpretation and analysis of presently available photographs and instrumental records to take advantage of this significant development in the Earth Resources Program.

W. R. Markey
April 25, 1968

PROFESSOR BRUNO B. ROSSI

Astrophysics at M.I.T. includes a wide variety of different programs. In fact, it is perhaps fair to say that optical astronomy is the only major field which is not yet covered, although we have plans to enter this field, hopefully in the near future.

Even a summary discussion of all activities in astrophysics at M.I.T. would take much more time than we have available this morning; therefore, I shall limit my remarks to a brief general outline of these activities while other speakers later in the program will, by the way of examples, describe two of these programs in some detail.

Let me begin with theoretical astrophysics. Research in theoretical astrophysics is being carried out at M.I.T. both in the Mathematics and the Physics Departments.

For a number of years Professor C. C. Lin and his group in the Mathematics Department have been working at the problem of the dynamics of disk-shaped galaxies. As I understand it, the method is to treat stars as molecules of an ionized gas replacing the gravitational forces for electromagnetic forces as the agents which determine the collective behavior of this medium. One of the important results has been the prediction of density waves capable of explaining in a very natural way the spiral structure of galaxies. A related program, again in the Mathematics Department, is that of Professor Hunter and Professor Toomre, who have developed a theory which explains the bending of the galactic disk as due to a close passage of the Large Magellanic Cloud about half a billion years ago.

A second theoretical program concerns the structure and evolution of stars and the physics of matter in the stellar interior. Professor Iben and Professor Rose of the Physics Department are active in various aspects of this field; I shall quote here only the results of one of their investigations. By comparing the computed evolutionary development with the observations on the temperature and luminosity of stars in globular clusters, it is found that the age of the globular clusters is about nine billion years, which is consistent with the accepted value of the Hubble constant. It is also found that about thirty percent of the matter in the universe is in the form of helium, which is consistent with the big bang theory and with the 3° K radiation that appears to fill the whole space with uniform density.

A third line of research in theoretical astrophysics is that pursued by Professor Morrison and Professor Sartori. Essentially the aim of their work has been to construct and develop physical models for a variety of observed celestial phenomena. X-ray emission from cosmic plasmas, evolution of supernovae remnants, quasars, pulsating stars are among them. Of the many new ideas and of the many results that have come out of this work, I shall only mention a new general theory of supernovae, which applies to supernovae of both type I and type II, and which affords a convincing explanation for the time variation in the light emission from these objects.

In a group by themselves are some research activities aiming at providing a test of general relativity. Among these I should like to mention first an experiment suggested by Professor Shapiro, based on a prediction of general relativity, to the effect that the speed of light depends on the gravitational potential, decreasing as the light ray approaches a massive object (which incidentally is the opposite of what happens to a beam of material particles). Measurements of the radar echoes of Mercury and Venus, performed at the Lincoln Laboratory, did, in fact, detect this additional delay when the radio waves passed in the vicinity of the sun. The magnitude of the delay was found to agree with the theoretical predictions.

A second test of general relativity is now being planned jointly by Professor Shapiro, Professor Burke and other members of the M.I.T. radio astronomy group. The purpose of the experiment is to measure the deflection of radio waves from distant sources passing in the vicinity of the sun.

This brings us into the field of radio astronomy which, under the direction of Professor Barrett and Professor Burke, is particularly active at M.I.T. The radio astronomy program includes observations of the absorption and emission lines of the OH radical, of the recombination lines of hydrogen, of the isotropic 3° K radiation, arising supposedly from the big bang, of the variable quasi-stellar radio sources. The M.I.T. group has played a key role in one of the most ambitious and remarkable observational programs of modern astronomy. I am referring to interferometric measurements with base lines of thousands of miles which have been made possible by the development of highly stable atomic clocks. As part of this program, radio stations have been operated simultaneously at the Lincoln Laboratory of M.I.T., the National Radio Astronomy Laboratory of Green Bank, the Hat Creek Observatory of the University of California, and the Chalmers University Observatory at Onsala, Sweden. The very large separation of the stations has provided angular resolution far in excess of that of optical telescopes. For example, studies of the OH regions have demonstrated structures of the order of 1/100 second of arc, and an unresolved component in the quasar 3C273B has been shown to be smaller than 1/200 second of arc.

Another major observational program at M.I.T. is x-ray astronomy. Professors Clark, Bradt, Overbeck, Lewin and Schnopper, among others, are engaged in different aspects of this program which includes balloon observations, rocket observations and preparations for future satellite experiments. Among the results of the balloon programs I should like to mention the observations of time variations in the intensity of several x-ray sources. Particularly striking in this connection has been a temporary four-fold increase in the intensity of the x-ray star Sco X-1, which occurred during a balloon flight last October. The increase, which took place in a time interval of about ten minutes, was followed by a decrease with a time constant of about thirty minutes, a time sequence reminiscent of that characteristic of a solar flare except that the energy involved was at least a million times greater. This, incidentally, is the only x-ray flare reported so far.

Among the results of the rocket program I shall only mention the observation of an x-ray source coincident with the radio galaxy M-87. The same source was also observed by Dr. Friedman's group at the Naval Research Laboratory. It is a very weak source and the observations are therefore particularly difficult. The fact that the results of two independent groups are consistent with one another lends considerable strength to the conclusion that M-87 is indeed an x-ray source. This conclusion is particularly significant because, in my opinion, M-87 is so far the only extragalactic x-ray source whose existence may be regarded as well established.

Last, but certainly not least on my list, are two research programs concerned, respectively, with the study of the interplanetary plasma and with the detection of cosmic gamma rays. All of the programs that I have mentioned are, to a greater or smaller extent, related to space activities. All of them would deserve much more than the few words I have spent on them. However, the last two programs hold a special place because it was through them that space research began at M.I.T. some eight or nine years ago. In fact, I should like to recall that the first two satellites whose instrumentation was designed and built here were the plasma probe Explorer X and the gamma ray satellite Explorer XI, both launched in the spring of 1961.

This is one of the reasons why we thought that it might be appropriate to single out the subjects of interplanetary plasma and gamma ray astronomy for a more detailed presentation. The other reasons, I am sure, have become apparent after you heard about these subjects from Professor Bridge and from Professor Kraushaar.

B. B. Rossi
April 25, 1968

PROFESSOR NEVIN S. SCRIMSHAW

At present and for the foreseeable future, the food which man will be eating in space must be taken along with him. The estimates of the quantities of foods required are based on recommended dietary allowance. It is not generally realized that these dietary allowances are based on a very limited amount of data and a large amount of ignorance. To be sure of covering the needs of nearly all the population and to allow for this ignorance, very large margins of safety are often included. In the case of the vitamins and minerals where the take-along weight is small, it does not matter if the estimates are two or three times greater than the requirements. In the case of protein, where the recommendations are in excess of one gram of protein per kilo of body weight per day, we need to know requirements with much greater precision.

A study to determine the variation in the protein requirements of young men has been completed in the Department of Nutrition and Food Science. One hundred M.I.T. students, in groups of ten, were placed on a diet very low in protein for 15 days. During the first few days on this diet, they adapted maximally to it and thereby reduced their losses of protein from the body to a minimum. This was measured by the total urinary and fecal nitrogen during the last few days of the study. Allowances were made for integumental and sweat losses, enabling us to determine the range in protein requirements under the conditions of ordinary living. It turned out that the average requirement is considerably less than one gram of protein per kilo of body weight; in fact, just under 0.38 of a gram of protein of the quality of that in egg and milk. Moreover, a range of 0.28 of a gram to 0.48 of a gram of protein will cover the needs of nearly all of the population.

Thus, it is now possible to think in terms of a basic requirement of perhaps half of the amount of protein currently recommended and, if the astronauts were carefully selected, perhaps as little as one-third of the amounts now considered necessary. Unfortunately, the situation is complicated by the fact that there are a number of factors to which astronauts are exposed which tend to increase their protein requirements.

During millennia primitive man had to respond to dangerous situations, even on an empty stomach, by fighting or running away. Initially, epinephrine secreted by the adrenal medulla under the stimulus of the autonomic nervous system accelerates the breakdown of liver glycogen to glucose. Once the immediately available glycogen stores in the liver have been utilized, however, the mechanism which fasting animals and man have evolved to assure the necessary energy to meet such demands is the so-called stress mechanism whereby hormones from the anterior pituitary gland stimulate an increase in glucocorticoid hormone from the adrenal cortex. This in turn stimulates the release of amino acids from the muscle which pass into the blood stream, are taken up by the liver, and can be used by the liver to make glucose. In synthesizing glucose, however, the nitrogen of the amino acid molecule is unused and appears in the urine as an increase in the urea excretion.

It was not necessary to send M.I.T. students into space in order to study the effects of the stress reaction on protein requirements. All that was required was very careful metabolic studies during final examinations. The results of studying some 30 undergraduates can be summarized as indicating that in about one-third of the students there was a significant stress response throughout the reading period and the final examination period which resulted in additional nitrogen losses of ten to twenty percent and a corresponding increase in protein requirements at the time and during the time thereafter to make up the losses which had been sustained during the stress. For another third of the students, stress responses were apparent on individual days, but were compensated for on other days so that there was no net loss of nitrogen and hence no net increase in protein requirement. The final third, presumably those valiant individuals from among whom future astronauts will be recruited, showed no stress response whatever during the examination period.

There is, however, a source of stress to which all succumbed and that was the necessity of performing useful work without sleep. During the first day without sleep, everyone adapted quite well.

But, the second day without sleep, when the six student volunteers were expected to continue performing useful tasks, stress was evident. The result was an increased urinary nitrogen loss and therefore an increased protein requirement.

The subjective consequences of a reversal of night and day associated with prolonged East-West travel are recognizably disturbing. We arranged for a complete reversal of the day/night cycles of 19 M.I.T. students so that instead of breakfast at 8 o'clock in the morning, it was served at 8 o'clock at night. Lunch was eaten at 12:30 a.m. and dinner was at 6:00 a.m. Sleep and activity were readjusted accordingly. The first day without sleep, during which the reversal was taking place, was again well handled by the students. On the second day, however, a significant stress response was observed which gradually tapered off during the ensuing four or five days. When they were returned to a normal day/night cycle the stress response again occurred in the same manner.

Professor Richard Wurtman of the Department of Nutrition and Food Science is interested in the implications of interference with the external stimuli coordinating diurnal internal rhythms. Individual organs such as the kidney, the adrenal cortex, and the liver show diurnal patterns of physiological activity. These patterns are synchronized by the cycles of sleep and activity and light and dark to which we have become adapted. Professor Wurtman's laboratory has observed that when rats are deprived of these external cyclic stimuli, these various internal rhythms go out of synchronization. He believes that the loss of coordination may have adverse effects on performance.

Professor Wurtman has also demonstrated that there are rhythms in the way that the body utilizes food. In the rat, which is a nocturnal feeder, the activity of tyrosine transaminase, an important enzyme in the liver, is at its peak during the night hours, and is at a low ebb during the daytime hours. This suggests that if a rat were confronted with a sizeable amount of dietary tyrosine during the daytime, it might not utilize this amino acid as well as it would during the night. These studies have already been extended to human volunteers and Professor Wurtman has observed marked rhythms in the levels of the essential amino acids in blood plasma and in certain of the key enzymes even in fasting subjects.

The activities of the astronauts involve a certain amount of necessary physical work for maintenance of both the mission and their own cardiovascular and muscle tone. Although it has long been stated that there is no increased protein requirement for muscular work, recent studies in Japan and in Germany have indicated that individuals consuming adequate protein for ordinary activities show a loss in lean body mass, a decrease in serum albumin and hemoglobin when they perform heavy muscular work on the same protein intakes. We have reinvestigated this problem by conditioning young men to be able to walk for two hours a day on a treadmill at four mph on a ten percent grade. This is beyond the physical capacity of most university students without a prior training period and involves the expenditure of an additional 1,000 calories. A level of protein intake adequate for the individuals when they were not working and in the range mentioned earlier was found to result in some decrease in lean body mass, albumin, and hemoglobin over a period of 44 days.

The effect was not due, however, to an increase in nitrogen excretion in the urine, as would be the case if it resulted from increased protein needs for the muscular work per se, but could be accounted for almost entirely by the increased sweat losses. These individuals lost from a minimum of 1100 ml for a student from Florida, to 1600 ml during these two hours of work even though they wore minimal clothing and were in a cool environment. Other students and our own direct measurements of the nitrogen content of sweat indicate that under these maximum sweating conditions sweat contains about 0.7 milligrams of nitrogen per milliliter. This can result in a sizeable cumulative sweat loss of nitrogen, thereby adding to the requirement for protein to replace it.

Considerable losses of body weight due to water losses have been reported with most of the space missions so far. Many conditions tend to increase the sweat loss of astronauts, including the necessity of doing work in a confined space, the hampering effects of a space suit, the reduced partial pressure of the cabin atmosphere, and in the past, imperfect temperature control, and the like. The potential sweat losses of astronauts will obviously have to be taken very seriously into consideration in computing protein requirements.

A logical way of maintaining body tone in a confined environment is through isometric exercises. Such exercises, which consist of pushing or pulling against a fixed object, are capable of building muscles and also of maintaining good body tone. We were surprised to find, however, that when we substituted two 45-minute periods of intense isometric exercise for two hours of dynamic work in individuals on a relatively low protein intake, there was a deterioration in their performance when they were periodically retested on the treadmill. We monitored lean body mass by counting whole body potassium in the M.I.T. whole body counter in the Physics Department of Professor Robley Evans. The animal body has a small amount of naturally occurring isotope of potassium which can be measured with appropriately sensitive equipment. The ratio of the isotope (K40) to the remainder of the potassium in the body is fixed and, under normal conditions, the relationship of potassium to cell mass is constant. But in this case, we observed from the whole body counting that there was a loss of potassium not accounted for by measuring lean body mass through another method, the dilution within the body of a small dose of deuterium. The problem is still under investigation, but it appears that toward the end of the isometric contraction, which in these studies was sustained for 30 seconds, there is a leakage of potassium from the cell. Some of this potassium is excreted by the kidney before recovery can occur. Thus, there is small but cumulative loss of protein which eventually has a measurable effect. Certainly if isometric exercise is combined with minimum protein intakes, the availability of potassium will have to be taken into account in planning for the use of this type of exercise on space flights.

Let me turn now to a brief consideration of some of the problems associated with food for use in space. At the present time most of the food is dried, much of it freeze-dried. This is satisfactory for missions of even reasonably long duration, but when the trip extends from weeks into many months and years, and when food must be stored under conditions of a space capsule or a fixed planetary base for long periods of time, there is a gradual loss of volatile substances from the food. These volatile materials carry with them odor and flavor, resulting in a loss of palatability of the food. Moreover, there is a passage into the atmosphere of volatile materials of the capsule from some of the structural materials. These come into equilibrium with the food. While this could be prevented by using metal cans instead of plastic containers, the weight required would be excessive. These trace materials from food and structural material such as plasticizers not only interfere with food palatability but more importantly, may accumulate unless there are specific mechanisms for their removal. These volatile substances are present in such incredibly small quantities that the methodology is difficult. Professor Phillip Issenberg in the Department of Nutrition and Food Science is using mass spectrometry and gas chromatography to explore these phenomena.

Dried foods present another problem. It has long been known that when the moisture content rises above a certain level, non-enzymatic browning occurs which interferes with the availability of certain of the amino acids. This reduces the quality of the protein. It would seem simple to avoid this problem by keeping the moisture content low, but Professor Marcus Karel has recently demonstrated that with very low levels of moisture in dried foods another undesirable reaction occurs--the oxidation of fat. The moisture concentration at which this occurs varies with the nature of the food. It is usually in the range of one to two percent, but for different food systems there are different optimum moisture ranges to avoid both of these undesirable reactions.

I mentioned earlier the possibility of reducing the weight of protein which must be taken along. But, there still is the problem of the weight of the food needed to supply calories. If the calories are to be supplied from carbohydrates and protein, with a caloric concentration of four calories per gram, then about a pound of food per day man must be taken along. If these calories could be supplied from fat, with a caloric concentration of nine calories per gram, the amount of food required would obviously be less than half. The amount of fat that can be supplied in the diet is limited, however, by the fact that when fat represents an excess proportion of total calories ketone bodies are produced which, in turn, have a toxic effect and would interfere with the performance of the individual. Professor Sanford Miller in the Department of Nutrition and Food Science has been exploring a group of new compounds which do not occur in nature. They can be synthesized from petroleum hydrocarbons and have a caloric density close to that of fat, seven or eight calories per gram. Their remarkable characteristic is that they are harmlessly metabolized through carbohydrate pathways. He is able to feed an experimental animal a maximum amount of fat to the point where ketone bodies would be produced, and then substitute the remaining calories in the diet by one of these compounds without increasing the ketones or slowing growth.

The compound most studied is 1, 3-butanediol. There is no reason why this could not be used as a calorie source in human diets, except that it tastes something like Campari, the bitter Italian liqueur. Since this particular compound obviously will be not be acceptable in large quantities as a dietary staple, Professor Miller is continuing the research to find additional compounds in this family, hoping to find one which will combine caloric density and high palatability.

There will finally come a time when take-along food will not be sufficient, and there will need to be a regeneration of waste materials to provide part of the food. When the time comes, it seems likely that this will have to be done through single-cell organisms. This is not as radical as it sounds because we have been using the single cells of food yeast for more than 50 years. Several million pounds of food yeast go into baby foods in the United States. The principal difficulty with the single cells, however, which we have been actively exploring here at M.I.T., is that rapidly growing cells have a relatively high concentration of nucleic acid as an inherent characteristic. Part of the nucleic acid molecule is made up of purine which must be metabolized to uric acid rather than urea. Man and his fellow primates, along with the Dalmatian coach dog, lack the enzyme uricase to break down the relatively insoluble uric acid to the more soluble allantoin. Consequently, when for either genetic or dietary reasons, levels of uric acid in the blood become high, there is danger that uric acid crystals will be deposited in the joints, giving rise to gouty arthritis, or in the kidneys, causing kidney stones. Both are obviously highly undersirable for astronauts.

It is clear from the investigations to date that either the amount of single-cell protein allowed in the diets will have to be restricted, or a way will have to be found of treating it so that the purine content will be reduced. In the meantime, our studies with M.I.T. students have indicated occasional individuals who, for genetic reasons, have relatively high uric blood levels even when consuming normal diets. It is quite clear that these individuals should be screened out of any program involving prolonged isolation in space.

I would emphasize two conclusions at this point. It should be obvious that all of these investigations, while capable of making important contributions to space exploration, have equally important applications to the solution of man's food problems here on earth.

It should also be clear that there are still a large number of biological problems associated with man's expected prolonged presence in space. Many of these are at present only dimly perceived and hence the research to overcome them cannot be centrally programmed. Possible biological problems of man in space must be explored in an imaginative and sophisticated way. The institutional grant from NASA to M.I.T. has proved an effective mechanism for stimulating such research.

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N. S. Scrimshaw
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PROFESSOR EUGENE B. SKOLNIKOFF

One of the most enlightened and, I believe, exciting conditions agreed to between NASA and M.I.T. in establishing the Center for Space Research was one that called for the social sciences to be included as an integral part of the Center. The general charge in the Memorandum of Understanding was that: ". . . research is to be encouraged on ways and means to expand the search for useful applications and on the economic and social impact of our national involvement in space exploration." The charge was sufficiently broad to allow research in areas of existing and planned emphasis in the rapidly growing social sciences at M.I.T. (incidentally, larger and of higher quality than is yet generally realized outside the social science fraternity), but nevertheless clear enough to encourage new departures in directions of direct interest to the space program.

For the first several years, the social science research supported by the Center, though concerned with multidisciplinary subjects, was carried out within traditional social science departments, being divided between the management sciences and political science. More recently, as I shall mention briefly later, we have begun to explore ways of bringing together effective resources from both the natural and social sciences to study problems of particular social concern.

The majority of the social science research supported by the Center has been concentrated in two broad areas: 1) the process by which technology from large scale government R & D is diffused into the economy, and 2) the impact of the space program on international relations with special attention to the formulation of American foreign policy. Other work in both management and political areas was supported in part by the Center, but these were the main themes and the ones I propose to report on today.

Let me take the work in the management sciences first. In September 1964, a research program was initiated at the M.I.T. Sloan School of Management to seek better understanding of the technical innovator and of his role in transferring technology from government-sponsored R & D efforts out into the industrial and consumer marketplace. The program has been directed by Professor Edward B. Roberts.

The focus of the research has been divided between studies of 1) the creation of new product ventures and new technology divisions in <u>existing</u> companies, and 2) the creation of <u>new</u> companies by entrepreneurs seeking to exploit technological advances, the two areas being identified as "internal entrepreneurship" and "spin-off entrepreneurship." The "spin-off" label refers to the fact that the technical basis of the new company often spins out <u>with</u> the entrepreneur from some other existing organization. To date most of the research efforts have been directed at the latter area of <u>new</u> enterprise formation and growth.

During the past four years, Professor Roberts has investigated over 200 companies founded by ex-employees of several M.I.T. laboratories and academic departments, of a government laboratory, of a not-for-profit corporation, and of an industrial electronic systems contractor. Of these, four M.I.T. labs alone were found to have produced 105 new companies, and four M.I.T. engineering departments have spun off an additional 50 companies.

The performance records of these firms certify that most of them are generally successful. As a minimum statement, they seldom fail; only about 20 percent have gone out of business during their average four to five years of existence thus far. Although the typical company is still small, the growth curve of total current sales of all these spin-off companies closely parallels the growth in total billings of the founding organizations from which they have spun off with an average delay of about six years.

It is worth noting that most of the companies studied had their start as government contractors or in selling products to the defense/space markets. However, at the present stage of company development--and remember, the companies averaged only four to five years of age when studied--an average of 40 percent of the business of the M.I.T. spin offs comes from the commercial market. This tendency toward non-government sales increases significantly during each year of company history, the most successful companies in particular making special efforts to lessen their dependence upon the government.

An important characteristic of the advanced technology markets served by the spin-off companies studied is that the Federal government's role as a customer provides the catalyst needed. Defense/space requirements for high technical performance provide support funds before the otherwise high prices required by the advanced technologies would be justified by industrial or consumer markets. Yet once moving with the stimulus of the initial government market the new technologically-based company seems able to penetrate into new areas of application, diffusing the technology while building corporate sales.

The social, economic and technological implications of these several general findings are important ones. They demonstrate that the flow of entrepreneurs out of advanced technical organizations into their own businesses can create significant technology transfer as well as impressive commercial and economic impact. During the past several years many regions of our country, numerous cities, a host of universities as well as a number of other countries are catching on to this fact of life. They are attempting to transfer the growth potential of entrepreneurial technology transfer to the economic development of their own geographic areas. The data indicate that such attempts are worth pursuing, and that government encouragement of these entrepreneurial flows can be an important factor. There is much more to this problem of developing what has come to be called in this country the "Route 128" phenomenon.

Professor Roberts' more detailed examinations of these enterprises have focused on the founding entrepreneurs, the influences upon and the extent of technology transfer from government-sponsored R & D to the market, and the factors affecting the growth of these enterprises. Time limitations prevent more than brief mention of some common findings that emerge from the research on the spin-off entrepreneurs as well as from the studies of the internal entrepreneurs. In both settings the technical entrepreneur has been found to be a man of youth and advanced technologically-based education, coming from a work environment in which the exploitation of advanced technical ideas is being pursued. Even during childhood the eventual technical entrepreneur has often had some influences of career orientation toward self-employment that have affected his personal development. The notion of going into business for himself has long been a serious consideration of both the internal and the spin-off entrepreneur.

Within the large corporation and possibly also in the large government laboratory, the young would-be entrepreneur often finds attitudes and policies that discourage him and that work to prevent successful technology transfer from the R & D lab to the market. Many of these young venturers cannot even get to the point of active pursuit of their interests within the firm and leave these large organizations to set up new companies. The volume of this outflow is illustrated by the research finding that from one major company studied, 32 spin-off firms now account for sales more than double those of their parent. And those individuals who do not quit the company may still find themselves failures as a result of a corporate anti-entrepreneurial approach. Professor Roberts has suggested that new forms of organizational incentives and managerial philosophies may be needed for the large organization to retain and to stimulate the would-be entrepreneur.

Both internal new business ventures and external new companies were found to have their success dependent in part on the degree of exploitation of advanced technology. The data on the new enterprises studied permitted the identification of youth, developmental (versus research) orientation, and quickness of attempted technology utilization as some of the influences essential to effective technology transfer from laboratory to market. Moreover, in both internal and external settings the degree of advanced technology used was found as an important stimulant of the success attained by the venture. Thus not only does technology transfer occur; it contributes critically to the achieved business success. Professor Roberts has found a variety of other factors that also affect the growth and profitability of the new technical enterprise, including motivational and managerial forces.

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The research results reported thus far sustain the original premise that the difference between mere technical invention and successful market-place innovation is largely attributable to the personal role of the entrepreneur. Better understanding and management of him and of the personally-based technical innovation process will lead to more rapid and more beneficial technically-based corporate and economic growth.

In addition to this detailed work on the formulation of technologically-based enterprises through the movement of scientists and engineers from government-supported facilities, there has been more general attention to the question of technological transfer. In line with the work led by Professor Roberts, it has been our conviction that a major part, probably <u>the</u> major part, of the process of transfer of technology from space and defense R & D to the civilian economy occurs not through product and process transfer, but through human factors of a variety of kinds.

One of these factors is the creation of new technological enterprises as described above. Others are the movement of scientists and engineers from defense-oriented to civilian-oriented industry--sometimes within the same company--the feedback of new scientific and technological information to the education system, and the interaction between the academic community and defense industry.

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These and other human factors in the transfer of technology were spelled out in detail at a highly successful conference sponsored by the M.I.T. Space Center in 1966. The proceedings of the conference and the papers presented will shortly be published as a book by the M.I.T. Press, edited by Professors Gruber and Marquis.

In the political science area, the research focus has been quite different. Here the emphasis has been on the political and policy implications of the space program, in particular the effects in the international arena. There is a connection with the more management-oriented effort--in fact a paper co-authored by Professor Gruber laid out the relation between industrial R & D investment and the U. S. trade position--but, by and large, the research has been more heavily foreign-policy oriented.

A major segment of the work was devoted to a study of the interaction of science and technology and American foreign policy, with the space program providing many of the case studies to illustrate the relationship. It is a commonplace to observe that science and technology have sharply altered the meaning of power, the pace and character of international relations, and the actual conduct of diplomacy. Yet, in the actual formulation of policy, in the appreciation of the role of scientific and technical aspects of issues, in the anticipation of effects of future scientific and technological developments, and in consideration of the potential conscious use of science and technology for policy purposes, the reality has too often appeared to fall far short of the cliches. The study was designed to explore the actual relationship of science and technology to foreign policy, and to analyze the foreign policy process in the light of that exploration.

The analysis took a series of foreign policy areas, including not only the new areas arising directly from new technology such as space and atomic energy, but also more or less traditional areas--national security, bilateral relations, foreign aid, international organizations--and explored for each the relevance and significance of science and technology.

The clear conclusion was that scientific and technological considerations are important and _critical_ elements of many of the _central_ issues of foreign policy, _more_ important to _more_ issues than is generally realized or acknowledged in the policy process. The all too-common belief that the technical aspects of foreign policy issues can be handled as simple matters of fact, to be provided by any technically trained person is wide of the mark. Rather, at the level of significant choice in policy issues, when there was an important scientific or technological component, that technical component almost invariably was uncertain, open to widely varying interpretation, controversial, and closely interlocked with the political alternatives open to the policy maker. That is, the policy choices available were often a function of the technological uncertainties and choices, and, equally, the technological choices were a function of the political choices. It was interesting to see in how many cases the technical elements of an issue could not be adequately represented independently of the policy alternatives themselves. And, it might be added, it was interesting to see how often the technical elements and implications of an issue could be and were represented in different ways according to the policy biases of the scientist or engineer, even when there was general agreement on the technical facts.

These conclusions have important implications in the U. S. government, and the study analyzed existing Federal government machinery that attempts to integrate science and technology into the making of foreign policy. In general, the results of this analysis were not encouraging, particularly in examining the ability of the Department of State to bring to bear technical/political expertise on important issues. The most difficult task is not obtaining technical inputs, especially from relevant government agencies, but rather developing the capability to consider such inputs objectively, which is necessary for the State Department to maintain independence of judgment from the technical agencies of government. In this respect, the Department of State has not been notably successful, too often being the "prisoner" of agency biases and policy preferences because of almost total dependence on the agencies for technical/political information and analysis. This situation is particularly inadequate when considering opportunities for using science and technology consciously as an instrument of foreign policy (particularly in the space area). It is changing today since the study was completed, but slowly.

This study resulted in a book: Science, Technology and American Foreign Policy published by the M.I.T. Press, which in effect laid out for the first time the breadth and significance of the relationship across the board of science and technology to foreign policy, as well as making the points noted. It also speculated about the likely significance to international relations of future developments of science and technology. I believe it is fair to say that we have not adequately recognized today, let alone for tomorrow, the real meaning for international relations of new technologies. How does or should technology alter our concept of sovereignty, of independence of action, of control of territory in an era when the scale and scope of technology and its effects so often cannot be considered within a national framework alone. What are the lessons for our fundamental assumptions about the wisdom of "political interference" in technology and even in science? Can we always afford to have, from the viewpoint of international peace and stability, whatever will come from the laboratory? In any case, how do we bring under adequate political and human control the new powers that science and technology will continue to bring to the world?

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One area in particular stands out as requiring new thought and new ideas. It is the question of developing the international regime that global technologies will increasingly force on the world. Problems of international control, ownership, regulation and allocation of benefits, will arise increasingly as technology leads us to exploit resources in an international environment or gives us the power to take actions with effects outside national borders. Present models of international machinery do not appear adequate to the job that will be required in the oceans, in space, in the atmosphere, in furthering cooperation in conserving scarce resources, and so forth. We need new inventions. What must they do and what should they be? This range of questions is the agenda for future work.

In addition to this study, there have been several others in the international area, but I shall mention here briefly only two. One was a study on outer space and arms control carried out by Professors Clemens and Bloomfield, that resulted in a Space Center monograph and ultimately publication as a book. The work reviewed the history of both the Soviet and the United States approaches to arms control arrangements for outer space from 1955 to 1966, and it considered the military, political, and economic factors conditioning the approaches of these major space powers. The forces impelling both governments to reach an accord on deployment of weapons of mass destruction in 1963, the challenges made to that accord, and the factors leading

Washington and Moscow toward a more comprehensive and formal treaty on outer space in 1966 and 1967 were examined and analyzed in detail.

The other, which is still in progress, is a detailed study of U. S./French space relations to determine just how political, industrial and security factors determined the actual technical relations, including cooperation, in space-related matters between the U. S. and France. Both countries are interested in international cooperative programs, each with different motives. When the total picture of space technical relations is examined, however, the picture that emerges is curious; that is, in some areas there is less cooperation and interaction than policy pronouncements would lead one to expect; in others, there is considerably more than one would think general U. S./French political relations would allow. The actual situation, and the reasons behind the various decisions that have been made, should be quite illuminating in the overall context of understanding how technology is actually used in, and how it affects, foreign policy. This study will also open the question of industrial interests in international space relations, which has been a controversial and little explored subject. I might add that much of this work in both the management and the political science areas has been of direct relevance to, and has directly fit into, some of our undergraduate course offerings in the Institute, particularly in relation to our Science and Public Policy program.

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So that aside from the research results themselves, it has had a direct effect on our educational program.

So much for the general areas of social science research supported by the Space Center. This research, and other underway that I have not mentioned, is directly related to the space program or to the impact of space activities. Some of it involves a degree of multidisciplinary cooperation, but by and large the work is encompassed within normal disciplinary boundaries.

In part, as a result of the existence of the Space Center, and in particular the interest of NASA in furthering more broadly-based research, we have begun a study at M.I.T. to explore a more fundamental response to problems of broad social concern. We start this examination with the conviction that an institution like M.I.T. has a major responsibility to understand and to seek solutions to important social problems. The record of the Institute through its first century demonstrates that this response to society has always been high on the agenda. More and more, however, important social problems emerge as a direct result of scientific and technological advance and yet do not conform neatly to the traditional disciplinary organization of a university.

What can we do about focusing research resources on new problems, what institutional innovations are required, what are the key problems we should be tackling?--all are questions that have been the concern of a special seminar that includes among its members key academic officers and faculty at the Institute.

It is too early to report the results of these deliberations, but a specific plan is being developed for broader discussion. If some of the ideas do materialize, they are likely to have a profound effect on the future pattern of development of M.I.T., for they will make easier the kind of cross-disciplinary approach to major social issues, without abandoning the disciplines, that is typically so difficult to mount at universities today. Student involvement will be an essential component, both for educational reasons and as a means of meeting the growing demand of students to be involved in problems directly relevant to the society in which they live.

Whether we can succeed in this remains to be seen, but if so the M.I.T. Center for Space Research will have served the essential catalytic function that brought it about.

E. B. Skolnikoff
April 25, 1968

GOVERNOR JOHN A. VOLPE

On behalf of the Commonwealth of Massachusetts it is indeed an honor and a pleasure to be here and to take this opportunity to honor Mr. James E. Webb in recognition of his many contributions to American progress in space research and exploration. We are delighted to present to him this citation which reads: "To James E. Webb, Administrator of NASA, on the occasion of the dedication of the Center for Space Research at the Massachusetts Institute of Technology."

The Center for Space Research will prove to be a great asset not only to M.I.T. but to the Commonwealth and the Nation as well.

Our state has always taken great pride in the heritage of excellence that has been handed down from generation to generation, and the dedication of this new multi-million dollar research center surely will be another milestone in our quest for expanded knowledge.

The M.I.T. Center for Space Research will be further testimony in this amazing technological age that in Massachusetts "Brainpower" is our most important product.

And in this day and age, just ten short years since the dawn of the Space Age when Russia and the United States launched Sputnik One and Explorer One, respectively, the world has certainly placed a premium on the talents that will be employed in this new research center.

I need not remind anyone here today of the rapid and amazing progress of space technology, nor of the tremendous potential that exists in this field. In fact, future accomplishments and benefits of our space program are almost as unlimited as the solar system in which we live.

The space program in America provides us with technology on a scale so vast and varied that even the professional is hard-put to keep up with it, never mind the layman!

In those ten short years since man-made satellites were first sent into orbit there is hardly a single field of scientific endeavor that has not been touched by the space program.

Just as World War One gave impetus to the development of the airplane, and World War Two greatly accelerated nuclear technology, the space age is providing similar impetus--only in a peaceful manner, I might add thankfully, in such areas as data processing, micro-miniaturization of electronic components, communications, weather forecasting, and a host of others.

"...Every known discipline, scientific or otherwise, is potentially affected, and we are seeing an integration of human and material resources on an unprecedented scale."

Even more important is the stimulation that our ambitious goals in space bring to the young people of our nation and to our educational system. This stimulation is hard to measure, but I am convinced that as a result of the attainments of the many highly skilled people in the space program and our astronauts, the American people have set higher goals for their own accomplishments.

We could, of course, continue to sit solidly on the surface of the earth and look at the stars and the planets through telescopes and wonder. But it is inconceivable to me that this nation, with its long history and heritage of ingenuity, freedom, and bold spirit of adventure would have the resources and the ability to find out what the rest of the universe is like and yet be so disinterested that we fail to do it.

Either we are a nation that is alive, alert and aware--and one which is eager and anxious to explore and learn--or we are not.

It is as simple as that. And I am delighted that here in Massachusetts, the men at M.I.T. are laying it on the line--are saying, "Yes, we want to know." . . "Yes, we want the answers." . . "Yes, we're ready to break through the barriers."

We are delighted that M.I.T. is again in the forefront in the breakthrough toward a new frontier of knowledge.

This Institute has again demonstrated its excellence as a force for imaginative and creative thinking.

This new building, 100,000 square feet devoted to research into a field that was unheard of when most of us were of college age, will take its place proudly in a community and a state that are fast becoming space-oriented. . . a community and state that are paving the way to a brighter future for all mankind.

J. A. Volpe

Goethe once wrote that there are three tests of a building: ". . . That it stands on the right spot. . . that it be securely founded . . . and that it be successfully executed."

I would add one more test--that the building serve a great purpose. I am confident that the people here at M.I.T. will give this magnificent new structure, the Center for Space Research, a great human purpose as mankind seeks new passages through the barriers of the unknown.

From the new Space Center, I am sure, will come the ideas and concepts that will stir men's hearts and fire their imaginations.

Mankind is well served through the exploration of the unknown. I can think of no better place for such research than here at M.I.T.

My congratulations to everyone involved in this important undertaking, and I am confident that the new Center will be the home of many breakthroughs in the future.

J. A. Volpe
April 25, 1968

DR. JAMES R. KILLIAN, JR.

In reviewing the early history of the NASA-M.I.T. discussions concerning an expanded program of space research at M.I.T., I recalled data that indicated there were 150 members of the M.I.T. faculty who were already engaged in work relating directly or indirectly to space. There were some 500 graduate students --as a matter of fact some 15 percent of all of the graduate theses currently then being done at the Institute, related directly or indirectly to the space program. So you see, the evolving space program has had a profound effect on academic institutions as well as on many other kinds of institutions. It is most timely, therefore, that we celebrate the fact that the universities in this country have been able, thanks to sound policies and very perceptive understanding on the part of the administration of NASA, to share importantly, and to contribute importantly to the space program.

I cannot help but have a certain touch of sentiment on this occasion because we have the good fortune, in dedicating this Space Center, to take part in one of the celebrations that marks the tenth anniversary of our national space program. Some of us can recall very vividly the aftermath of Sputnik in late 1957, and I wish to reflect on a document that has some related historic interest. It is dated March 5, 1958. It is a memorandum for the President. The subject is: "Organization for Civil

Space Programs. The preamble to this document reads this way: "As you know, there will soon be presented for your consideration civil space programs for the United States which will entail increased expenditures and the employment of important numbers of scientists, engineers and technicians. This committee (the President's Advisory Committee on Government Organization) in conjunction with the Director of the Bureau of the Budget and your Special Assistant for Science and Technology has given consideration to the manner in which the Executive Branch should be organized to conduct the new program." Then the memorandum continues on to discuss all the various ways in which our government might undertake to administer a space program. But then it comes to a conclusion: "Recommendation Number 1: We recommend that leadership of the civil space effort be lodged in a strengthened and redesignated National Advisory Committee for Aeronautics." That, I think on March 10, 1958, was the beginning of the preparation of a bill that was subsequently introduced in the Congress in early April following the report. This led to the subsequent congressional action wherein Congress passed the bill, and in July the President signed the Space Act of 1958; all of which I think sets some kind of record for the creation of a new agency in our government.

As I ran through this document there was still another section of it that struck me as showing how little we recognized, in those days, what we were moving into. One paragraph reads this way: "N.A.C.A. now spends around 100 million dollars per year. A civil space program may eventually entail . . . may eventually entail"--it says!--"additional annual expenditures." (There was an understatement if there ever was one.) The report went on to say: "It is obvious that important changes in N.A.C.A. will be required by such an expansion, and the agency may have some difficulty in assimilating the additional staff and functions."

Well, that was in March 1958, and incidentally, this proposal to the President which he subsequently approved, was signed by Percival Brundage, Director of the Bureau of the Budget; Nelson A. Rockefeller, Chairman of the Committee on Government Organization; and myself. So I do have some sense of, as I say, sentiment, on this tenth anniversary occasion because one cannot help but be tremendously impressed and encouraged by what has happened since NASA was established in 1958, and for all the hopes and the expectations of those in Congress and the Executive branch of the government that were involved in creating this new civilian space agency. I think they all have reason to feel that it has worked wonderously well and that what has been accomplished over this ten-year period is dramatic and spectacular beyond the dreams of any who had anything to do with the formulation of the program in those early days.

J. R. Killian, Jr.

Here today, I welcome the opportunity of expressing my admiration for what has been accomplished by NASA, and particularly to point out, in doing so, that for more than half of its life it has been administered by Mr. James Webb. What I have been saying about NASA is in part a tribute to what he has accomplished in administering this new, vital civilian agency and its exciting program.

Mr. Webb, as I am sure all of you know, is an attorney, a businessman, but one who has served his government in an extraordinary variety of ways. I first came to know him when we were both members of a committee called Management in Government under President Truman's administration. Mr. Webb had already served a period as Director of the Bureau of the Budget, and this committee was concerned with that part of the Bureau's activity that dealt with management and organization in government.

Shortly after that, Mr. Webb moved on to the State Department, where he became Undersecretary of State, and while there some of us here in the Cambridge community had a rather special opportunity to come to know him, and to recognize his understanding of the contributions which universities can make to the government, and how best the universities can be helped in making those contributions.

J. R. Killian, Jr.

The State Department came to M.I.T. at that time--I think largely under the instigation of Mr. Webb--and asked us if we would undertake a study that related to some of the problems involved in the Voice of America. These problems at first glance seemed to be primarily technical, but as we looked at them it became clear that there should be a consortium of disciplines brought to bear if they were going to be solved in an effective way. This led to the more general program called Project Troy, to which Mr. Webb contributed much in concept and form. Project Troy was an interdisciplinary undertaking that involved physicists, electrical engineers, psychologists and sociologists, and anthropologists and others from the social sciences and the humanities. This new interdisciplinary program was formulated to deal with a specific problem. The resulting experience was of such excitement to the people who participated in it that they came to the administration of the Institute and said, "We think this kind of activity in a university is so important that we hope M.I.T. will find a way to continue it." And so we did, and it was out of this experience that our Center for International Studies was subsequently established and remains a flourishing part of our program at M.I.T. today. Again, we express our thanks to the help of Mr. Webb and his understanding of how this sort of thing could really work in the university environment.

J. R. Killian, Jr.

Mr. Webb went back into industry after his period in the State Department but soon was called again to the government, and this time, as you know, to be the Administrator of the National Aeronautics and Space Administration. Here his understanding of political process, his skill in dealing with professional people, and his devotion to the public service, plus his extraordinary perception and understanding of how our universities operate, how to protect their integrity, how to find ways in which they can be of service to the government in programs such as the space program, has permitted him to make a very great contribution.

So we have many reasons to be delighted to welcome Mr. Webb here in this academic environment and on this occasion.

J. R. Killian, Jr.
April 25, 1968

MR. JAMES E. WEBB

I do think it is extremely important that associations among men permit them to learn from each other how to move forward with large endeavors which have different requirements from small endeavors. It was Dr. Jeome Wiesner who telephoned me in Oklahoma where I was sitting on the platform of a Chamber of Commerce Friday Forum honoring Senator Robert S. Kerr, and said that President Kennedy and Vice President Johnson would like me to come to Washington to talk about heading up a space agency. It was the present Secretary of Defense, Mr. Clark Clifford, to whom I appealed to get me out of the job so I would not have to take it. He laughed and said, "Well, I have been recommending you." So, in a way, these associations that come from common experiences of examining various needs of the nation, of trying very hard to create additional strength within the economic, social and political structures of our nation as we go about large endeavors are what I think I cherish.

If I have added anything to the understanding of how to work with universities, how to provide substantial resources without impairing their ability to grow stronger for their own purposes, it is because I have had this opportunity of association with men like Dr. Killian, Dr. Wiesner and another here, Dr. Jerrold Zacharias. It is because I have been very fortunate to find men like Drs. Hugh Dryden and Robert Seamans, who have added a component of policy judgment to the daily decisions that had to be made. It is because all of us had the good judgment to reach out to a man like Dr. Fred Whipple, from another institution, may I say, here in Cambridge, when overzealous desires to classify information important to research should have been subjected to searching inquiry. Dr. Whipple showed those who were in my view somewhat overzealous that the mathematics of the situation just did not support them. I think this was a very real contribution, but it also added a component of knowledge, of wisdom, of judgment in how to deal with important matters that relate to the freedom of scientific inquiry, to the opportunity on university campuses to proceed with the work the nation needs done in close association with graduate education, and not to build circumscribed barbwire-enclosed endeavors unless they are really and truly necessary.

I could mention others from other universities, like Dr. Albert Kelly, who have made great contributions to NASA. Professor Leo Goldberg has spent the last two years looking for a viable pattern by which the astronomers of this nation could work through an astronomy missions board of NASA, to examine what the nation should do over an extended period in astronomy, and the manner in which space vehicles could play their proper part with other apparatus used by astronomers, and to create new apparatus so that these outstanding men in their field project the needs of the nation. These men are prepared to sit and review the projects which we government men are considering from current funding so that their own ideas of what the nation might do, or ought to do, can be modified from their experience with the question of how many dollars should be allocated to a project that one astronomer or group of astronomers has proposed.

It is this interaction between long range planning, modifying concepts of what ought to be done in the reality of what can be done, plus one other factor--the relationship of men of action and men of science--that I believe is extremely important in the future of M.I.T and of all institutions. I should like to point to an example. At Houston we have created a capability to receive both men and materials returning from the moon, to keep them in isolation in a manner satisfactory to the Public Health Service so that the health of the nation will not be impaired by the return to the earth of harmful substances or diseases, and then to permit some hundred or more scientists around the world to receive parts of these samples. In doing so we must maintain the means by which we shall preserve certain parts in the same form as they were received so that many years from now, if new methods of analysis come about, the samples will be available for the utilization of further scientific techniques.

Now I come to the men--a situation where on land donated by Rice University, NASA will build a structure that is available to the lunar and planetary scientists where they will not need a government pass or any permission from any government person to come, to associate, to have a library, to have seminar rooms, and yet, to step across the fence, so to speak, or through the gate and to talk to an astronaut and say, "Say, Bud, what was it like up there when you picked up that piece of rock?" or whatever it is that the interaction between the man of science, the man of intellect can have, and needs to have, with the man of action.

We have been considering in astronomy the same kind of thing, except that the interaction will be at the end of the telemetry link, assuming that we are able to put up proposed structures like the one ten miles long for radio astronomy. The importance for astronomers using this device is to have a thorough knowledge of the communications link and what is possible, what is not possible, and how to use these new capabilities in redirected ways. Real time planning for examination of phenomena which may not have been preplanned is a very, very important element. I think Dr. Killian has pointed to the essential need for wisdom, for correct policy, and then for men in the arena of action to so relate their activities that they have mutual respect and confidence and the work does indeed get done.

The idea of serendipity is certainly not new. In a project that Dr. Killian mentioned and on which Dr. Wiesner, Dr. Lloyd

Berkner and others worked, there was produced the scatter concept of propagation for communications systems which was so essentional for our military services that it was financed by a grant of 300 odd thousand dollars from the State Department to M.I.T. It has given something of great value to our national security. It was also, in effect, a grant from Congress of $50 million in the form of a blank check to develop the state of the art of communications satellites that gave us SYNCOM after we already had the capability of random flow altitude satellites. This, in turn, gave us a tremendous increase in the capability for communications all around the earth. Again, it was the fact that vehicles carrying men in large Apollo systems moved so fast that we had to transfer the control from one ground station to another, that led us to the decision that we must have a single point of control of these very large, complex and long duration missions. As the earth turned, we knew we had to have three stations at least to maintain out-of-sight communications with these vehicles. Furthermore, we had to have a communications and telemetry system which would bring the data in to one single point of control where we had over-the-shoulder supervision at three levels, where one man examining one astronaut's performance could integrate his activities one step up with a man looking at broader systems and then one step up again, ending with the man in charge of the mission. The system also required that all men could be in constant communication with each other and where individual and general directions could be issued as needed; or where the supervisors could, by turning a button, look over the shoulder and examine the performance of any individual or group operating in the complete system.

Two things, I believe, are important here. First of all, we are able to communicate over this system to any place on the surface of the earth with automatic switching, automatic monitoring and high speed terminal equipment, getting a station, say in Madagascar, in half the time it takes you to dial a local number. With this equipment, no human judgment is involved in sending the message whichever way around the earth it can go best, and with the monitor determining whether or not a circuit is degrading by a small amount as it feeds directly into a computer. With 25 different contractors around the world operating this sytem, with application of this knowledge to the entire communication system of the planet Earth, we have an upgrading by several factors of the overall capability of the human race to use an already in place communications system.

In a related area you also find that, when the Gemini astronauts bring back wonderful color photographs of the Earth taken with hand-held cameras and a petroleum exploration company engineer looks at these pictures and says, "These photographs tie together a lot of other data we have," they can then go to the placed indicated by all the data, including this overview provided by the Gemini photographs, and a major discovery is made. This has happened. Industry does not talk much about it, not to government people anyway, but the point is that many of the activities involved in these large systems which operate in the atmosphere and in space make all we have done before much more valuable. This experience is certainly not unknown to scientists because it is what you are doing all the time. That is the basis of the system.

Let me say now that some appreciation has been expressed to NASA for the support which has come to the Massachusetts Institute of Technology and to the outstanding men and women who have been at work here in these various aeronautical and space-related fields. I should like to turn it around and say, "I should like to express the appreciation of the United States government to these scholars, to these researchers, to these engineers and technical people for what they have done." In fact, they have taken national resources and converted them into knowledge, into understanding, and into the kind of working models of apparatus that industrial companies may then manufacture at a profit to themselves and with great service to the government. They have also advanced the theoretical foundation on which much of the future must rest. Incidentally, the fact that they have chosen the sun as a major object of study is a matter of no small importance to this nation and to the human race. Obviously, my time will not permit my going into details as there are so many outstanding men, so many outstanding projects, all of them making major contributions, that it would take a very long time for me to express appreciation to all of them. To mention one without the other is something I should prefer not to do.

I should only like to say that the appreciation expressed to NASA should really run the other way. First, because of men like Robert Seamans who had fifteen years at M.I.T.; I, who had a few years of association with these men, did have from them a basic concept and understanding which did, in fact, work when put to use in practice. When I say that, I am speaking of grants and contracts to universities in this nation of over half a billion dollars within the life of this agency and of grants and contracts to this institution of almost a third of that amount, some $132 million. This has not been a small matter. I am speaking now of the fact that here at this institution, in addition to this effort in a building called the Center for Space Research, there has been brought together an interacting group of social scientists who are examining many of the problems that society faces as it looks at the use of total systems engineering and total systems management projects.

If the Wright brothers contributed much in the field of aerodynamics because they did use a wind tunnel and the coupling of a machine with wings and control surfaces, they also con-

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tributed to the understanding of what it means in a three-dimensional control environment to have a machine that was so constructed that it had enough built-in stability as to be maneuverable. In a way, the integration of the controls of the Wright brothers' machine was the main difference. It is this integrated type of control in constructing economic, social, and political machines that can operate in a turbulent environment and which are not so stable that they are not maneuverable, which I believe is one of the greatest contributions that will come from our efforts in space.

The intellectual concepts required to move from the old aeronautical concepts when I learned to fly (I was told when you hit bad weather, go down and fly where you can see--on the tree tops; and very shortly when we had the instruments, we were told to go up and fly where there are no rocks in those clouds) produced a major change in the whole way aviation developed. We have seen the conversion from thrust/drag/lift ratios to the ratio of thrust to inertia which the astronaut has to consider. Furthermore, the new vehicle is out of the atmosphere and is in dynamic equilibrium with respect to the Earth. If the astronaut wants to change it, he must apply a thrust to overcome inertia and he must do it very, very precisely. In this, the human mind moves all the way through from two-dimensional control to three-dimensional control, from the limits of a vehicle operating in the atmosphere or in the water to one with almost unlimited capability in a state of dynamic equilibrium beyond the atmosphere.

So, I should like to just leave you with this thought. If our cities today are a turbulent environment, if problems to meet poverty, need for education among the disadvantaged groups in our society, better housing, or even a better way to bring the 1300 jurisdictions that you can see from the top of the Empire State Building in New York City together into a viable pattern of operation and coordinated activity, then it is, I believe, these concepts that have come out of motion, out of single points of control for those things where they are needed, for ability of human beings to work with someone at several levels, looking over their shoulders and applying judgment, that will ultimately provide the tools needed to meet those problems.

The Wright brothers surely proved that you could fly. They also proved that you had to put in enough power to give you the lift to get off the ground. You did not achieve flying speed without power. Many of our efforts to meet current conditions never have enough power input to have the slightest chance to get off the ground, to achieve flying speed. The hardest thing I think Dr. Killian and his associates dealt with in the early days of the space age was how to get enough power to overcome inertia and gravity and the drag of the atmosphere to get up to 18,000 miles an hour so you could achieve orbital speed. The first achievement was the ability to get in that power.

Later came the tremendous problems of control and guidance and the developing of a means by which various small miniaturized apparatus could solve very, very complex problems. When a man like Edwin Aldrin works out a thesis for his doctorate degree on how to do a rendezvous while moving at 18,000 miles an hour around the Earth, as a student here at M.I.T., gets elected as an astronaut and becomes a man of action to prove out his theory, which he did, you then see the true nature of these kinds of rapid translation from theoretically correct concepts into workable systems that involve man and machine that somehow we must know more about.

I should like to mention another matter. The capacity of the human mind to understand and use the forces that are here in this universe is not over. The ability of man to find ways to cooperate and build institutions like M.I.T., or the Commonwealth of Massachusetts, or our Federal system is not over. There is a need today for centers of power for good government outside government. We have thought of a government of divided powers as providing many checks and balances. In many ways, this system of divided powers results in an inability to achieve the kind of maneuverability and flexibility we need. We see Walter Heller using the title "fiscal dynamics." We have concerned ourselves with governments of laws and not of men. Yet we now face the situation where a certain amount of instability and maneuverability must be available and there must be a way that men can be trusted to use the controls in those machines in those systems.

One thing that NASA is doing here now is pioneering with how we create these kinds of capabilities outside the government. For a long time we worked in the Academy of Sciences, through the Space Science Board, and moved on to the point where they accepted a grant from NASA for three Columbia University scholars to study the basic research needs in public administration. We have worked very closely with the new Academy of Engineering, and there is now in existence an Aeronautics and Space Engineering Board which deals with the same problems the Space Science Board deals with for the National Academy of Sciences.

However, in reality, how does the profession of engineering operate within the structure of our society, within our corporate structure, in the schools of engineering and also in examining the large engineering systems that government itself must employ, and the professional problems of ethics, of interests, of standards and so forth? There also has recently been formed an Academy of Public Administration and NASA has opened up the ranks of its workers and the projects that we have. Eminent scholars in the public administration are now beginning to examine how men like me do our work because, while we react to the things we have to do every day, these scholars with their disciplinary background can interpret truly what we are doing and how it relates to the pattern of the accepted theory and doctrine better than we can ourselves. This morning in the panel discussions it was interesting for me to hear Professor Skolnikoff mention that there were certain young, competent, entrepreneurially oriented men who had spun off, as he said, out of the M.I.T. laboratories and had formed some large number of new companies. He also stated that the corporate form of organization was sufficiently rigid in this country and that many similar men were spinning off out of the larger corporations to form their own companies. I think also he might well ponder whether the extension of those kinds of studies could be made to the entrepreneurially oriented government administrator, such as Dr. Robert Seamans' position in the government and Dr. George Mueller's position in charge of a $3 billion a year segment of NASA's business. Dr. MacAdams' position in charge of a $350 million segment of advanced research and technology development and his predecessor, Dr. Raymond Bisplinghoff, now head of your Department of Aeronautics and Astronautics, might also be subject to the same type of study. We should study how NASA can best use 200 project managers operating at a multi-million dollar level, while financing another 200 in industry also operating at a multi-million dollar level, and bring these 400 men together in the totality of an engineering system operated in a fish bowl atmosphere with TV cameras on them and still be able to explain to Congress and to the newspaper men what it is they are doing, why they are doing it, and why it ought to be done that way.

Let me give you one quotation from Mr. Rufus Miles, who was with me in the Bureau of the Budget, went on to be Assistant Secretary in the Department of Health, Education and Welfare, and is now at the Woodrow Wilson School in Princeton. Speaking of the social setting of the day and the need for something more than specialization and division of work, or indeed the present pattern of theory and doctrine in the field of administration and management, he said:

> "Specialists must be organized, led and given the opportunity to be free and creative by persons in our society who perform the role of weaving the work of the experts into a meaningful pattern. If the specialized occupations are the warp of the fabric of our society, then the politicians, the public administrators, the philosophers, the clergy and their associates are the woof. When the warp of a fabric is strong and the woof is weak, it quickly becomes frayed."

I am not going to talk much longer, but I should like to turn now to how it seems to me men in universities, working with men in these large undertakings, might think more about the next things to do. My father, as some of you have heard me say, used to always say, "The most valuable man is the one who knows what to do next." The phrase was used this morning by, I think, Dr. Bridge when he said, "How do we interpret these data?"--meaning the data that he was getting from space vehicles which was quite large in amount. Also he said, "Much remains to be done theoretically and experimentally to be able to interpret the data." A great deal of data is available from these large systems that have been operated successfully, from OPA during World War II all the way through the Marshall Plan, the various systems for building ballistic missiles, and NASA. We have a large amount of data, but much remains to be done theoretically and experimentally. It seems to me further that those of us in the business need to do what I believe Dr. Kraushaar said, "We must produce the evidence that we know what we are doing, or at least that we know what we are claiming to do."

It seems to me there are data which theoretical model builders in universities need to check against the anthropological types of observers. To support these studies, NASA and AEC have opened their whole range of operations and their officials to responsible scholars working on responsible projects. We have a very interesting study just starting by Ambassador Foy Kohler who recently returned from Moscow. He was Under Secretary of State, ran the Voice of America when it was a $100 million operation, and so he understands something of the problems of the administrator. He is going to devote three years to a study of what the Russians have received from their space program in comparison with what they hoped to receive, and compare that with what the United States has received. I think this is going to be a very interesting study. It seems to me that we need to do more of this in an interaction relationship between scholars in universities and action programs, particularly with some historical evaluation against things like the OPA, which was a remarkably effective organization for several years, bringing the inflationary spiral down to about a two percent price increase during the war. Many people do not know the difficulty of that organization or the things we used that made it effective.

As to the second ten years of the space age, I can say this. First of all, the funding has continued for the approved projects like Apollo. We do have the money to proceed to fly out the nine Saturn V missions that we expect to accomplish between now and the end of 1969. The fact that we could fly a first Saturn V mission and have it come out so perfectly from launch right on the second and recovery at the end of a driving re-entry into the Earth's atmosphere at almost lunar return speeds on the first flight of this giant vehicle was, I believe, quite remarkable and a great tribute to Dr. Stark Draper and his associates here who did the guidance system. The fact that on the first test of that apparatus they went some 18,000 miles, re-entered the Earth's atmosphere, turned over when they heated up, skipped out again, and went another 1000 miles and landed just a very short distance from the expected point of impact after this second re-entry, is an indication of the capability which has been built into this equipment by the work of the university and of industry. The fact that the second flight of the capsule worked so perfectly on the first flight of this giant rocket was also extremely important.

Now, however, we come to the second flight of Saturn V when we had troubles. We had troubles with the big hydrogen engines. We had a Pogo effect, a five-cycle per second oscillation coming from the very large F-1 engines. I am sure you all know that those five engines drink propellant at three tons per second and deliver about the amount of power of 6000 Boeing 707 airplanes at cruise speed. This is a giant application of power and the engines did come into synchronization. They did produce a certain Pogo effect, longitudinal oscillations, and everyone thought the engines in the second stage were broken apart by that oscillation. We had enough instrumentation to prove, and enough ground laboratory ability to reproduce on the ground, the fact that that was not the cause at all. It was a simple failure of a three-eighths inch fuel line that was carrying a large amount of hydrogen under heavy pressure, at about 100 to 125 miles an hour through that line. The break was not due to the vibration. However, 36 stories up from the bottom there was a lateral conversion of this Pogo effect into forces that did, in fact, break part of the rocket off. We have pictures of particles falling off this giant rocket as an airplane went right up with it and took the pictures while the rocket was about 50 or 60 miles above the earth. The point is that the payload went on and we succeeded in accomplishing much including bringing the payload back, and we learned a great deal from it.

Our Apollo program team now has sufficient knowledge of how the system works and enough analytical capability to take the readings from those instruments and to place before me the recommendation that we put men on the next flight of that big rocket even after the failure of two engines in the first stage, one engine in the third stage, and this piece dropping off the rocket. So, if anybody wants to take over the responsibility of making that decision, it's all right with me. The technical crew has strongly recommended that the next flight of that rocket be with men on it.

I should like simply to point out that this capability exists at the beginning of the second ten years and that we have as a nation now not the terrible inability, but the ability, to truly do what the world expected us to do ten years ago after Sputnik. We are not proceeding at the same pace as the USSR. They are devoting about twice as large a portion of their GNP as we are to these aeronautical and space activities. They are flying at a much accelerated rate. They are flying more large payloads than we are. They are trying to go to the planets about three times for each one mission that we undertake. Also they are building a rocket system larger than the Saturn V which is a very large rocket system.

I leave you with this thought that, although the budgetary situation is such that the President has not recommended, nor has Congress approved, the continued build-up to the planned rate of six Saturn V's and six Saturn 1-B's a year, has not approved the forward missions to the planets and the development of further manned space capability beyond Apollo, there is a capability to match what has to be matched. Much of that rests in institutions like M.I.T. If it is necessary to do the job we have to do in the world, to protect our vital interests, to prevent being denied entering into and having access to the space environment, it can be done from the base we have. But it would be a mistake to say the present programs will do it or are doing it. We are dropping behind. The programs for the future are not being funded. There is going to be a hiatus of flight under the kind of conditions with which we are faced. Yet the policy of NASA at the beginning of this new ten years is to put increasing amounts of funding into the advanced research and technology fields and not to squeeze these funds as the operational systems are being underfinanced. Our purpose is to be able to make the new and better systems of the future rest on modern technology and not on an obsolescent technology. Again, it may be even more important in a time when the funding is going down. To give you an illustration of what I mean, the total work force built up from about 75,000 some seven years ago to 420,000. We have laid off 140,000 people out of that group. We have disbanded one-third of the work force in the space program within the last two years, but at the very least it is important in a country of this kind to maintain the capability to build up again. So let me say that I believe M.I.T. has made tremendous contributions from the first technical report of NASA in 1915, which was based on work at M.I.T. and signed by Jerome Hunsaker, until today and this institution has played a major part in the nation's advances. It will continue to do so. Its work is admittedly more important than if we were planning to land on Mars in 1973 or 1975 if we had the funds, because when we do decide to go to and land on Mars, we shall have a better system because of the work being done here.

Let me thank you again and to say I am delighted to be here to help dedicate this building. However, the appreciation should run from the government, from the taxpayers if you please, to M.I.T. and the faculty and the engineers and the people, the technicians in the laboratories here, rather than the other way.

J. E. Webb
April 25, 1968

MR. HOWARD W. JOHNSON

Mr. Webb, I think I speak for everybody in this room when I say we want to take this occasion, in part, to salute you and to pay tribute to the dedication and leadership that you have given to the whole field of space science and to the interests and the activities of young people in this field. The example of your public service stands before us as an exceptionally high standard of the level of our commitment and the degree of excellence that we wish to bring to this challenge. And so it is with great pleasure that, in speaking on behalf of the Institute community in welcoming our new home for space research, we also salute you and your colleagues at NASA.

It was just five years ago that this Center was formally organized at M.I.T. and, as Dr. Killian has pointed out, the field itself is only a decade old. Space represents a resource that opens for mankind an entirely new horizon of awareness and influence and potential. It is, and will continue to be for some time, something strikingly new and extraordinary. Yet our approach to space research is grounded firmly in the history and the tradition of this Institute. I refer here to the approach of technology: the imaginative application of resources--human and physical--to the solution of man's needs and to the fulfillment of his dreams. Increasingly at M.I.T., this approach has taken the form of interdepartmental laboratories and centers as well as the traditional departments, where a variety of skills, perspectives, ideas and concerns can be brought to bear on complex issues.

As you know, the first dramatic example of this kind was the Institute's Radiation Laboratory during World War II. By drawing together physicists, electrical engineers, mathematicians, biologists, chemists, architects and historians, the Institute created a new kind of intellectual force that was applied to the problems and to the developments of radar in the 1940's. The impact of that intellectual force in the form of alumni of the Laboratory is still strongly felt throughout the world of technology, and many of those men are here today. The Laboratory had taken on a task that was not limited by scientific, by technological, nor even by political barriers. Its performance, in a real sense, was a measure of the value of multi-disciplinary dialogue and research.

Following the war, the ideas, the men, and the resources of the Radiation Laboratory were translated and transformed into other laboratories, such as the Research Laboratory of Electronics, which continues to be an innovative center located at the interface of the physical and the life sciences. Today, RLE is one of many interdisciplinary centers which combine lively academic theory with experimentation, and bring faculty and students into an active partnership for developing new concepts, new approaches and, in the end, new benefit for mankind.

H. W. Johnson

And so we see major interdisciplinary activity carried on at the Lincoln and Instrumentation Laboratories and, on the campus, at the Center for Materials Science and Engineering, the Laboratory for Nuclear Science, the new Urban Systems Laboratory and, of course, our new Center for Space Research, now taking its place with these laboratories in new, handsome surroundings.

The opportunities afforded by this new building are very real: the laboratory space, the facilities and the instrumentation. But there is also a symbolic value to this Center as a physical entity. We look forward to the further contributions in education and research which our concerns with outer space will be able to make possible because of this new facility. In a symbolic way, this building will set a new standard for higher M.I.T. performance and achievement. By drawing together people from the physical, the social and the life sciences, from engineering and from management, this Center will be able to focus not only on the conceptual and the technical aspects of our space effort, but will be able to address the economic and the social repercussions that surround the exploration of space.

I want to stress that we have our eye on the long run in this field as well as the short run. We look beyond the moon, and we are in this activity to stay.

This broad perspective represents an especially important focus for our interests in space research, as it does in other fields. There are other important problems for the country in which we hope to be deeply involved, but this remains an impotant and exciting frontier for us. The achievement of success in this field will not proceed without consideration of all of the changes implicit in the technical, the economic, the political as well as the natural ecology within which it operates. For centuries scientific experiments have altered the environment they were designed to explore, but these alterations were minute. They did not upset the balance; they did not affect the total system. Today, the advance of technology and the scale of experimentation are very often as threatening as they are enlightening. And it is this broad vision, the total picture, which the Center represents in its multidisciplinary dimensions that is vital and necessary to our future.

There is still another dimension to the Center for Space Research. It is a source of steady science. To be sure, there is great drama and a special glory to any first launch--the sudden discovery and the sense of capturing new knowledge. All of us share in that kind of thrill, but that is only one aspect, one important focus of a vast program that is backed by the steady pulse of scientific excellence. It is the first step in a larger, more difficult process, if you will. I refer, of course, to the multitude of extended uses of space science, the endless by-products and spin-offs of our space effort. Their impact and their effect on our lives may be less dramatic but no less important than space flight itself. Already we see new developments in satellite communication, in weather forecasting and in man/computer communications which have great educational, commercial and medical value and potential. It has been predicted that miniaturization techniques developed in the space program may make it possible to reduce a room-size artificial kidney machine to the size of the actual organ.

There are numerous other examples of how basic research, fundamental to the space program, has had earthly and practical results. I think we are going to see many of these in the years ahead. This is what I mean by steady science--the creation of new knowledge that will enable us to pursue ends that are not necessarily linked with our initial space goals.

Finally, there are the people behind the whole program. Here in the Center for Space Research--as in the associated enterprises and other laboratories and centers--their effort, their devotion and their example to students is the most important aspect of our current effort and of our aspiration for the future.

Exploration, science, engineering, human knowledge--to these broader purposes we dedicate today M.I.T.'s new Center for Space Research. We dedicate it to the men and women who bring their perspectives and ideas and who learn from the insights generated from collaborative effort. To those who have opened this exciting frontier, we promise the fresh resources of a new generation, and to our students we promise the endless excitement of new discovery.

H. W. Johnson
April 25, 1968

PROFESSOR JOHN V. HARRINGTON

I think that while President Johnson has eloquently responded to Mr. Webb and accepted our new building which will house many of the activities of the new Center for Space Research, may I just for a moment supplement his remarks and speak, not so much for M.I.T. but for the large contingent of us who are housed in the building and whose research is encouraged and stimulated by the provision of such fine new facilities.

As has been pointed out several times, M.I.T.'s contributions to the national space program extend well back in time beyond the conception of our Center. But these contributions were neither limited to those of large groups in the large off-campus laboratories nor, at the other extreme, to faculty or graduate student researchers working in the small departmental laboratories. One of the most important purposes of the Center is to fill in the gaps in this spectrum of research activity and make it possible for the individual academic researcher, be he faculty member or graduate student, to be associated with a slightly larger group and to find greater opportunity to engage in this exciting new field. I believe that we can say that over the past five years since the Center became an official entity on the campus, it has indeed grown both in the size of its physical plant and, more importantly, in its intellectual membership so that it has made a good beginning in fulfilling at least one of its purposes. Now you heard much this morning of the spectrum of activities that are either housed or are shortly to be housed in the new building, and we invite you this afternoon to inspect the building and to meet some of the people and to see some of the experimentsthat are going on in it.

May I once again express on behalf of the Center's many researchers, its technical committee and its policy committee, the appreciation which we all feel for being able to work in such a fine new building and, more importantly, to further express the responsibility that we all feel to use it well.

J. V. Harrington
April 25, 1968