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REPORT OF THE CENTRAL REVIEW COMMITTEE

# *Useful Applications of Earth-Oriented Satellites*

NATIONAL ACADEMY OF SCIENCES
NATIONAL RESEARCH COUNCIL

# *Useful Applications of Earth-Oriented Satellites*

REPORT OF THE CENTRAL REVIEW COMMITTEE

SUMMER STUDY ON SPACE APPLICATIONS
Division of Engineering
National Research Council
*for the*
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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# NATIONAL ACADEMY OF SCIENCES

OFFICE OF THE PRESIDENT
2101 CONSTITUTION AVENUE
WASHINGTON, D.C. 20418

January 16, 1969

The Honorable Thomas O. Paine
Acting Administrator
National Aeronautics and Space Administration
Washington, D. C. 20546

Dear Dr. Paine:

Late in 1966, the Honorable James E. Webb, then Administrator of the National Aeronautics and Space Administration, requested the National Academy of Sciences to organize and carry out a comprehensive study of useful applications of earth-oriented satellites, giving priority to both technological considerations and assessment of relative benefits that might be achieved.

Under the general chairmanship of Dr. Deming Lewis, a Central Review Committee and a structure of specialized Panels were organized which, with invaluable assistance from your staff, have completed a study of a large family of potential applications and illustrative programs. The principal results of this Study are contained in "Useful Applications of Earth-Oriented Satellites: Report of the Central Review Committee," which is transmitted to you herewith. The Committee prepared this document after careful consideration of the detailed reports of the various Panels, and I am happy to forward it to you as the formal report of the National Academy of Sciences on the results of the Summer Study on Space Applications.

In view of the great interest, nationally and internationally, in the topics considered in this report, we believe steps should be taken to ensure its wide dissemination and ready availability to the public. Needless to say, the National Academy of Sciences will be pleased to join with the Administration in accomplishing this objective. While the Central Review Committee does not necessarily endorse the Panel Reports in every respect, their detailed work should be of substantial interest to specialists. These additional reports are being transmitted to you in separate volumes. Their specific conclusions and recommendations should be considered within the context of the overall report of the Central Review Committee.

With the delivery of these volumes, the National Academy of Sciences has concluded the Summer Study on Space Applications. We hope that the results of our effort will be helpful to you and others in the formulation of our national space policy and goals.

Sincerely yours,

F. Seitz

Frederick Seitz
President

Enclosure

NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES NATIONAL ACADEMY OF ENGINEERING

2101 CONSTITUTION AVENUE WASHINGTON, D.C. 20418

COMMITTEE ON SPACE APPLICATIONS
DIVISION OF ENGINEERING

14 January 1969

Dr. Frederick Seitz
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D. C. 20418

Dear Dr. Seitz:

The Central Review Committee of the Summer Study on Space Applications endorses to you, for transmittal to the National Aeronautics and Space Administration, its final report on Useful Applications of Earth-Oriented Satellites. This Study considered the employment of earth-orbiting satellites in roles and missions that are likely to have a direct and beneficial impact on the social, economic, and industrial activities of people in the United States and throughout the world. The Study attempted to identify applications where satellites may play some useful role in our daily lives and where the value of that role, properly judged, can justify the costs sustained in employing satellite systems for such applications.

The final record of the Study comprises several parts. One part is this Report of the Central Review Committee, which contains the conclusions and recommendations of the Committee and an account of why and how the Study was conducted. We recommend that this Report of the Central Review Committee be submitted to the National Aeronautics and Space Administration as part of the formal report of the National Academy of Sciences on the Study; and we believe that, with the approval of that Administration, it should be made available to a much wider audience, both within and outside the government.

In preparing its report, the Central Review Committee relied upon a large amount of excellent work by Panels in the various fields of application. We feel that the volumes that record this substantial and impressive contribution provide the principal foundation of our findings and will be of great interest to specialists. We recommend that these Panel Reports also be transmitted to NASA, and that they be made available to specialized audiences.

Summaries of the Panel Reports have been collected in a companion volume to the Central Review Committee's report together with a report by Dr. Thomas F. Malone, a Committee member who gave particular attention to the international aspects of space applications.

Two comprehensive conclusions emerged from the Summer Study on Space Applications. The first is that the benefits to be obtained from practical space applications appear to be large -- larger, in fact, than most of the participants in the Study anticipated and much larger than the cost of achieving those benefits. The second comprehensive conclusion is that an extensive, coherent, and selective program will be required to achieve these benefits. Some elements of such a program are suggested in the Committee's Report.

The Central Review Committee is deeply conscious that, in endorsing this Report to you, it is recommending that the federal budget for the development of practical applications of unmanned satellites be rapidly increased to a level two to three times greater than the current level of budgetary support. We are convinced that such an increase is necessary if opportunities for excellent investments in beneficial applications are not to be unduly delayed or missed by our nation within the coming decade.

Very sincerely yours,

W. Deming Lewis

W. Deming Lewis

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# THE SUMMER STUDY ON SPACE APPLICATIONS

In the fall of 1966, the National Aeronautics and Space Administration asked the National Academy of Sciences to:

> "conduct a study on the probable future usefulness of satellites in practical Earth-oriented applications. The study shall include obtaining considered reactions and recommendations of highly qualified scientists and engineers on the nature and scope of the research and development program believed necessary to provide the technology required to exploit these applications."

Subsequently, NASA asked that the task be expanded to include a consideration of economic factors.

Designated the "Summer Study on Space Applications," work began in January 1967, guided by a Central Review Committee (CRC) appointed by the Academy. To encompass so complex a subject, technical Panels were convened, with broad responsibilities for scrutinizing practical space applications in meteorology, hydrology, oceanography, forestry, agriculture, geography, geology, sensors and data systems, point-to-point communications, broadcasting, navigation and traffic control, cartography and geodesy. These Panels met over a period of several weeks during the summer of 1967. Their results were presented to CRC, which then made an Interim Report to NASA. In 1968, Panels on Points-to-Point Communications and on Systems for Remote-Sensing Information and Distribution were convened in response to the problems of data collection and data processing that had been exposed throughout the earth-resources area during the previous summer.

Each Panel was asked to postulate at least one system that would serve to demonstrate the foreseeable benefits from satellite applications in its field, as well as to indicate costs. A supporting group of cost analysts and economists worked with the Panels to help cost the systems and quantify the benefits where possible. These illustrative systems included the space segments, ground facilities, communications, and data-handling equipment. In many cases, the exercise also enabled the Panels to identify areas in which additional R&D was needed, over and above what NASA was already conducting in its space-applications program.

The major part of the Study was accomplished by the Panels; the function of CRC was to review their work, to evaluate their findings, and, in the context of the total national picture, to derive certain conclusions and recommendations. The Committee was impressed by the quality of the Panels' work and has asked that the Panel Reports be made available to specialized audiences. While the Committee is in general accord with the final Panel Reports, it does not necessarily endorse them in every detail. It chose to emphasize the major panel recommendations in its conclusions and recommendations, which are included in this summary report.

In the interval between summer sessions, two additional areas received attention. The first dealt with a harder appraisal of cost-benefit relationships by several senior economists—distinguished businessmen accustomed to appraising new technological development—who were added to the Central Review Committee. This group, together with the Economic Analysis Panel, reviewed and analyzed the Interim Report of the Committee, the preliminary Panel Reports, and the various cost-benefit studies sponsored by NASA. The second concerned a family of international problems that arise because satellites are inherently global devices; an *ad hoc* group explored the multinational implications of the applications systems that had been postulated, and discussed its findings with the Central Review Committee.

Between the summer session of 1967 and that of 1968, the Interim Report of CRC was circulated to all the government agencies with concerns currently or potentially in space-applications programs, with a request for comment. We have been grateful for the response. Many officials answered in great detail and were generous in providing supporting material. All their contributions have been discussed, not only by CRC, but by the Panel members who were directly involved with the substance of the critiques.

On 31 July 1968, over 100 representatives of these and other agencies visited Woods Hole to hear a presentation of the Study's findings. More than two thirds of this number remained for an additional three days of working seminars.

The Study was completed with the summer session of 1968, by which time nearly 200 people had been involved in the work.

## THE BACKGROUND

### *The Challenge*

Mankind faces two crucial management problems. One has to do with management of the quality and utility of our physical environment, i.e., land, air, water; the integrity of the space required for transportation corridors in all media; and the integrity of the bands of the electromagnetic spectrum used for communication. The other relates to management of the productive resources of planet Earth.

As we confront these problems, over 130 highly diverse nations are struggling to get along with each other during a turbulent era of rapidly rising expectations stemming in part from an explosively expanding science and technology. Fortunately, science and technology also offer potentially powerful new tools for measuring, describing, and understanding our environment, thus contributing to the knowledge that is prerequisite to intelligent management on a global basis. One very important tool is the earth-oriented satellite and its associated sensing, communications, and data-processing systems.

Today, just over a decade since the first artificial satellite was orbited, we can confidently describe several fields to which satellite technology is beneficially applicable. In two fields (meteorology and communications), satellites have already entered solidly into the area of economic usefulness. Applications in some other fields are imminent; for others, applications must wait upon more research. Benefits, in some instances, are predictably great; in others, they may be matters either of judgment or of reasonable surmise. What *is* certain is that space technology can be exploited for human good, specific practical objectives can be identified, and intensified policy planning for space applications—nationally and internationally—can begin.

*Categories of Space Applications*

The applications we have studied fall naturally into two broad categories, based on the uses of satellite platforms. One includes communications and navigation and traffic control, in which the satellite serves as a radio-relay repeater and/or position finder. The satellite's unique advantage of direct line-of-sight to many points, over large geographical areas, allows use of very high radio frequencies where the bandwidths available provide large information-carrying capacities. The characteristics of satellite platforms, and their orbital options, offer unparalleled opportunities to design communications systems of extraordinary scope and versatility. Commercial exploitation is well under way for some applications within this category.

In the other category, observations are made from the satellite over very large geographical areas of the earth, using visible light, infrared, or other electromagnetic radiation. A satellite can sense the thermal radiation in various parts of the spectrum from the land, sea, clouds, or atmosphere. What a satellite "sees" may be recorded as in a photograph or on tape, or the information may be relayed directly back to earth via radio. In this "seeing" role, the satellite should become a unique new tool to aid in our understanding of our environment and of the earth's resources. Daily use is already being made of satellite-gathered cloud images for meteorological purposes.

The use of satellites in these two categories poses different types of problems. In the first category, the dramatic new capabilities of satellites have already raised many thorny questions of national policy and of public and private interest. While many problems are unsolved, the interested parties are identified, and there is awareness of what must be done. In the second category, however, the ultimate users of the information from an observing satellite will likely be many and diverse, with interests ranging through agriculture, water-resource management, metropolitan planning, and geography. This diversity of interests and end-uses will present many special problems–social and political as well as technical–in matching the users to the data-gathering systems.

*Satellite Observations*

Compared with earlier methods of observation, a satellite has new and unique capabilities:

1) Depending on altitude, it can view areas of up to millions of square miles, all at once or selectively. This essentially instantaneous observation of large areas, under uniform illumination, provides a new dimension in our ability to comprehend and analyze what is observed.
2) It affords, in a single synoptic image, with geometrical simplicity, the information content that could otherwise be obtained only by assembling hundreds of images.
3) It can view continuously or repetitively, over long time-periods. With a power supply directly replenished by the sun, its life is measurable in years.
4) It offers easy observational access to regions that would be much more difficult, impracticable, or expensive to achieve by other means.

The volume of data that a satellite can gather will, in itself, pose new and complex handling problems, for nothing in our prior experience can match the volumes of information that can thus become available for analysis and interpretation for so great a variety of purposes.

*Feasibility of Space Applications*

The confidence that these unique qualities and capabilities of satellite platforms can indeed be exploited in practical applications stems largely from a combination of several factors:

1) The evolution of booster/launcher technology. The U.S. space effort has produced a whole spectrum of boosters, capable of delivering a few pounds into low-altitude orbits, or tons into more remote orbits. An important concomitant of this versatility is a marked decrease in relative costs (per

pound of payload) accompanied by marked improvements in the reliability of launching devices. The greater variety of launch vehicles also permits a better match between payload, orbit, and launch vehicle.

2) The improvement of guidance and control technology. The ability to maneuver payload-carrying platforms into particular orbits, then to maintain both the orbits and the attitudes of the payloads, now makes routine operations that were only marginally feasible five years ago.
3) The increasing lifetime of electronic equipment in space. (A similar improvement in certain kinds of mechanical devices is anticipated.) Today, a design specification of five to seven years' lifetime in orbit is considered reasonable for quite sophisticated devices, whereas a life expectancy of a year and a half was judged overly optimistic for the first simple communication satellites only a half-decade ago. The long-life potential has particular economic significance; for instance, doubling the lifetime of a satellite has the effect of halving the satellite and launching costs.

All this means that systems deemed uneconomic or even impracticable a few years ago now may be firmly within the payoff range. And, as the improvement continues, still more applications will warrant consideration. There appears to be no imminent natural ceiling to evolutionary improvement in launching and payload costs, complexity, and reliability.

This, then, was the base from which the Summer Study began its investigation of practical space applications, using several criteria to define "space applications." We were interested in uses of earth-orbiting satellites that would have direct and beneficial impacts, socially and economically. We looked at useful applications that, properly judged, would justify the costs. We considered, and eliminated, manned missions. Finally, we focused our attention on cases in which results could be foreseen in the next few years.

## THE SUMMER STUDY

### *The Approach*

The Summer Study conducted its deliberations along disciplinary lines, undertaking to:

1) Identify realistic space applications in the light of concrete needs within each discipline and of the benefits that might accrue.
2) Assess the degree to which satellite-sensed phenomena or satellite-collected information could satisfy these needs.
3) Determine the chief capabilities and limitations of platforms, vehicles, sensors, communication links, and data processors.
4) Postulate feasible systems as a means of identifying trade-offs. From such illustrative systems, some gross measure of understanding could be gained of the potential costs and timing that might be involved in satisfying each discipline's needs. Final system recommendations could not be made within the scope of the study.
5) Identify problem areas that would require attention, for the application to be realized.

### *Postulated Systems*

It must be stressed that the satellite systems described in the various reports of the Summer Study are *illustrative only;* they were postulated as a means of testing the notions that arose, for developing some ideas on probable costs, and for isolating areas in which additional work is needed. The danger of such an approach is that, with time, the systems may lose their hypothetical quality: people may become identified with particular systems and begin to defend their technical and economic characteristics. This is especially true in cases in which benefits are quantified and cost-benefit ratios are calculated. We have therefore tried to emphasize the conceptual quality of the various systems by liberal use of "hypothesized," "postulated," "illustrative," and similar modifying terms.

*Common Factors*

Satellite technology serving the requirements of the earth-resources disciplines in the aggregate revealed so many common factors, such as orbit characteristics, spacecraft orientation, sensor resolution, and spectral coverage, that thoughtful design philosophy could probably produce common-use systems with resultant lower costs than those of separate systems tailored for each discipline. Each discipline's special needs, however, impose certain constraints in both the research and operational phases.

Oceanography and all other disciplines concerned with earth-surface phenomena need instrumentation that must come from further research and development. In some cases, however, a single instrument can serve several disciplines. All disciplines, except possibly meteorology, require a combination of aircraft and polar sun-synchronous satellite platforms, chiefly in the R&D phase. Only meteorology, within this category, has identifiable sensing requirements for geosynchronous satellites. All disciplines anticipate urgent needs for training and education in the physical and biological sciences.

Development of spectrometric instrumentation and ground-based platforms is of first-order importance to all disciplines, for these are the laboratory tools with which knowledge of plants, soil, water, and other earth resources—the so-called "ground truth" inputs to operational systems—must be acquired.

*Changes in Space and Ground Requirements*

Six to eight years ago, because long life in orbit was an overriding consideration, satellites and their payloads were designed to be as simple as possible; the system complexity resided chiefly in ground facilities. Heavy investment in ground stations, as a means of improving life in orbit, thus was highly justifiable. Today, the state of the art for satellite design is sufficiently advanced that we can build satellites of increasing complexity and length of life. Thus, since beneficial space applications may require many ground stations, there may be increasing advantages in designing simple and inexpensive ground stations to work with complex satellites.

### *Use of Aircraft*

Several Panel Reports stress the value of high-altitude aircraft to develop and test sensors and to gather information for the postulated systems. In our Interim Report, we had highlighted the need for two aircraft, capable of operating up to 50,000 feet, as test vehicles for research and development in space applications. We are gratified that these have been provided.

### *Cost-Benefit Relationships*

The Study invited a number of economists and economist-engineers to analyze the systems postulated by the Panels, to estimate the costs of development and operations, and to appraise the foreseeable benefits. Their tentative findings were, in turn, reviewed in the 1968 summer session by an Economic Analysis Panel and by several consultants to the Central Review Committee.

The consensus was that these new and challenging fields of satellite and sensor technology are advancing so rapidly that caution must accompany any attempts at economic appraisal: the conventional cost-benefit analysis approach is not suitable for judging technologies in the fluid, formative state. Instead, in evaluating the different space applications, we were advised to use guides that have been widely adopted by business for planning and developing new products, processes, and services. The method comprises a sequence of four steps, interspersed with evaluation before each successive commitment, and usually spread over five to ten years.

1) Basic and exploratory research
2) Development: early design, limited testing
3) Pilot plant: market-testing programs
4) Operation: design, construction, and operation of commercial plant

The basic-research commitment involves substantial risk; cost and benefits are highly conjectural; judgment is necessarily the determinant. On the other hand, basic research is the least expensive stage. Subsequent to it, facts begin to accumulate, providing increasingly accurate material on which to base appraisals. By the time the greatest commitment is needed, the relevant costs and benefits can be defined, and sufficient data are available to aid the decision-maker.

Many of the space applications studied by the Panels fit into this sequential rationale. Some are challenging but of uncertain benefit; some warrant consideration of funding; others merit support now in competition with other pressing demands.

## FACTORS AFFECTING SPACE APPLICATIONS

*Social and Economic Influences*

We were impressed from the outset with the influence of the social and economic circumstances, national and international, within which space applications must function. One cannot make technical assessments of communications and earth-resource applications without taking account of the significant differences in the socioeconomic environments of various fields. During the last six or eight years, for example, there has been intense interest in the impact of the new satellite-communications capabilities in our economic and organizational systems. The interest in broadcast applications, for instance, has resulted in congressional investigations, academy and foundation studies, and Federal Communications Commission inquiries, and was a factor in the creation of a presidential task force on telecommunications.

In contrast with the activity in communications, operational applications of satellite technology in the area of earth-resource observations have lagged. This is due partly to the great number of technical uncertainties, partly to the less obvious opportunities for commercial investments, and partly to the greater diversity among ultimate beneficiaries of applications.

Such social and economic differences in the factors affecting various space applications have influenced the Study relative to probable or possible activities that the federal government might carry forward in the various fields.

*International Concerns*

The uses of earth-oriented satellites have inevitable international implications. They appear to have uniquely pervasive effects upon international problems of environmental and resource management. It is thus noteworthy that the United States may be able to develop satellite applications in such ways as to ease international tensions and offer solutions to world problems.

There have been encouraging precursors of the type of international arrangements that would be necessary to satellite applications; the earlier International Geophysical Year (IGY) and the currently developing World Weather Watch and the INTELSAT consortium are examples. A host of international organizations and engineering, scientific and professional societies (like the International Scientific Radio Union and the Committee on Space Research) have also proven effective in advancing the cooperative international approach to space.

Two aspects of the NASA program suggest directions for future international joint efforts in satellite applications. One is represented by the cooperative bilateral arrangements between the United States on one hand and Mexico and Brazil, on the other, to explore the use of aircraft in establishing ground truth. This sort of modest step establishes the basis for more extensive undertakings; it engenders acceptability and involvement. The second is the Automatic Picture Transmission system, designed in the early stages of the meteorological satellite to permit readout and data utilization by many nations at small cost.

The very breadth of certain international aspects of satellite applications suggests some guiding principles for the United States in moving toward the realization of these applications. They include these:

1) While refraining from overselling, the United States should use opportunities to educate foreign data users in the value and use of remote-sensing imagery.
2) To ensure a sense of participation by other nations, cost-sharing is desirable, although such cooperative efforts need not involve exchanges of currency.

*Enabling Actions*

Specific and timely federal actions are indicated if satellites are to be used effectively in ways envisioned by the Study. In the forefront are actions vital to the support of satellite applications, e.g., reservation of frequency bands for satellite-system use, and maintenance of clear frequency channels for certain applications. The International Telecommunication Union is planning a second space-frequency-allocations conference in late 1970 or early 1971. Any new requirements for frequencies should be developed in time for submission to that meeting, as the next opportunity for new space-frequency allocations may not occur until the late 1970's.

Many management problems will require solution. These include problems of coordination and cooperation—even of integration in some cases. The active concern and cooperation of all levels of management must be invoked. Middle levels, especially, will need to learn the use of new data-collection, interpretation, and distribution devices, so that these may be incorporated into agency missions. New orientations will be required before these new and powerful techniques can be absorbed into the basic operations of all agencies involved. Over the next two to five years, a series of programs may be needed to familiarize key operating personnel with satellite-gathered data, showing them how to use new methods for old missions.

Agreement among agencies will be required on both common and specialized R&D programs and on the applied research needed to bring operating data systems into existence. These matters will warrant priority in agency programs.

Each agency to be concerned with satellite applications will need to institute a general review—for the long term—of its mission and methods. This requires planning for the effective use of new techniques, and as to how each agency can best serve the public.

### *NASA's Space-Applications Program*

The current NASA program has generated a variety of exploratory studies in earth resources, meteorology, oceanography, and communications that present many choices for further effort. This program was reviewed and evaluated by the Summer Study and was deemed an excellent basis for inaugurating a broad national program in space applications.

## CENTRAL REVIEW COMMITTEE

## CONCLUSIONS AND RECOMMENDATIONS

Satellites are our newest national resource. The Summer Study has tried, in the last two years, to make realistic appraisals of their future usefulness in earth-oriented applications and their probable economic potential. We also considered the future and scope of the research and development program needed to provide the technology to accomplish these applications. NASA's mission to date has been science and technology in space, with heavy emphasis on manned flight. The technological accomplishments from NASA's programs allow us to conclude that space technology can be applied in a variety of ways that will contribute to the welfare of mankind and to the amelioration of certain of the world's problems, and that a number of practical uses can be realized within the next few years.

### SCOPE OF FUNDING

The benefits from space application are expected to be large—larger than most of the Study participants had originally believed, and certainly larger than the costs of achieving them. We are convinced, however, that an extensive, coherent, and selective program will be required to achieve these benefits.

The Central Review Committee has taken particular note of the present NASA launching schedule for R&D test-bed satellites in support of space applications in 1970 and thereafter. The average interval between launches is more than a year for both geosynchronous orbits (Applications Technology Satellite Program) and low-altitude polar orbits (Nimbus Program). Noting also that the program does not now provide for back-up launches, we must highlight several serious implications of this schedule.

First, and of paramount importance, the possibility is that failure of any one launch in such a program can extend to as much as three years the interval between opportunities to obtain R&D results from space. While the situation can be ameliorated to some degree by increasing both the "experiments stockpile" and the booster stockpile to permit a "call-up" launch in the event of a launch failure, we are convinced that a substantial increase in the present schedule of test-bed satellite launches—*to at least double*—is required if many important space applications are to be achieved within the next decade.

Second, high-calibre scientists and engineers are not challenged by, or attracted to, a program the launch schedule of which can only be characterized as "leisurely." The kinds of scientists and engineers needed for space applications will be attracted by a vigorous program providing frequent opportunities to try new approaches in space, and by a program strongly supported by the government.

We are convinced that the present space-applications program is too small by a factor of two or three, if we measure it in the light of the substantial opportunities that can be pursued effectively only if financial support is increased. Additional funding would permit expansion of the applications program, and would enable the nation to proceed toward critically needed investments in preparation for future operational applications systems. NASA would be able to carry certain work through the space-flight operational experimental phase, so that both the potentials and the problems of future systems could be thoroughly understood.

### *Recommendations*

NASA should give greater emphasis in its future programs and activities to earth-satellite programs with promise of beneficial applications.

Commit additional federal funds to support, in certain applications, both an expanded research and development program and prototype operations that will test out the technical capabilities and benefit potentials of possible practical applications.

Provide $200–300 million a year to support the space-applications program at a level that is in the best interest of the United States.

## RESEARCH AND DEVELOPMENT APPLICATIONS

It is likely that, in most space applications, it will be desirable for NASA to continue its technical program leadership beyond the research and engineering development stage into a phase of "pilot" operation, taking responsibility for the total space-flight experimental system: satellites, sensors, ground stations, test sites, and data processing. Potential user agencies, however, should participate actively in the planning and design of experimental programs, in funding and the establishment of budgetary controls, and in the evaluation of results. Moreover, personnel from potential user agencies should be involved at the working level in the development, design, and testing programs, not only to provide guidance from the standpoint of the ultimate users, but also to smooth the ultimate transfer of operating responsibility to the user agency. Only thus can both the potential benefits and problems of future operations be thoroughly understood by all concerned, and programs designed for maximum efficiency and benefits.

### *Recommendation*

NASA should accept responsibility for organizing the required space-flight operational experiments in close cooperation with potential users, and for providing the necessary satellites and related ground equipments to execute this important phase in the development of space applications. Personnel from potential user agencies should be involved from the beginning in the planning and design of experimental programs.

## INTERNATIONAL

In examining existing or suggested patterns for international space applications, the CRC has reached strong convictions on the importance of institutional arrangements that can be adapted easily and rapidly to functional requirements as they evolve with the technology. Imaginative organizational and political innovation may be as crucial as technical innovation in this sphere, especially where national systems interface with international ones.

### *Recommendation*

NASA, in cooperation with the Department of State, should continue to develop its international programs concerned with space applications, even in the face of budgetary problems, to ensure the development of a favorable climate for international acceptance and use of practical space applications, as they become technically feasible.

## INDUSTRY AND GOVERNMENT

Business and industry in the United States will be involved in practical applications of space technology. The implementation of the kind of space-applications programs we have recommended will require education and training of very large numbers of data interpreters and technicians, and a substantial number of high-level scientists and engineers. NASA and user agencies should cooperate with universities, technical schools, and industrial organizations in meeting this crucial manpower problem.

The list of ultimate users and recipients in space-applications programs is certain to be long and diverse. This situation presents special technical, social, and political problems in the couplings to and among users. Moreover, many proposed systems will not fit into existing patterns of governmental agencies and, hence, will present formidable management problems.

*Recommendation*

Studies should be made to identify clearly the interests and possible responsibilities of the various user agencies with the ultimate objective of creating appropriate, viable, and effective organizations capable of adopting and managing the new systems.

## MANNED AND UNMANNED FLIGHTS

We believe that the manned program has provided technological developments of importance to many aspects of space flight and the use of space. It is expected that this will continue. In particular, the large booster program, tailored to the requirements of particular earth orbits, will find applications in the orbiting of heavy payloads for a variety of purposes. Additionally, this program will provide significant opportunities to test sensors and to prove out techniques useful to applications considered by this Study. However, the use of manned vehicles *per se* does not at present appear necessary or economically desirable for the operation of the various space-applications systems considered by this Study. We believe that the systems proposed for providing near-term practical and economic benefits to the U.S. public and to mankind generally will be achieved more effectively and economically with automated devices and vehicles.

*Recommendation*

Manned programs must be justified in their own right; they cannot be justified in terms of space applications.

## METEOROLOGY/EARTH-RESOURCES SATELLITES

We are impressed by the fact that certain R&D programs give unusually great rewards; these are generally in areas of investigation that are on the steep part of the learning curve. Such an area is *sensor-signature research*—considered the single pacing element in earth-resources applications, and of value to other fields, such as oceanography and geology. R&D programs of this type are of greater relative importance in times of constricted budgets.

*Recommendation*

Support of sensor-signature R&D should be increased, as we are convinced that a modest investment in this area will generate great advances in our capability to evaluate the use of satellites for beneficial purposes.

We conclude that, in the near future, satellites can be flown with imaging sensors that can provide useful output data. A 200-foot resolution read-out capability is initially useful for such a system. A common approach involving forestry, agriculture, geography, hydrology, and possibly oceanography is feasible. Moreover, if a properly phased R&D effort could be started immediately, an operational system for over-all earth-resources information seems realizable within a decade, if the results of R&D are favorable.

*Recommendations*

NASA should promptly initiate a pilot program to provide pictorial information in familiar and immediately useable form. This early system, which could be of the Global Land Use (GLU) type described in Panel Report No. 1 (Forestry-Agriculture-Geography), would furnish much of the understanding required for future, more advanced systems.

The potential value of side-looking radar for geology, which would contribute to this understanding, should be explored.

Planning (with appropriate check-points) should be started for the evolution, within 10 to 12 years, of a substantially broader system with more sophisticated sensors. A facility of critical size is necessary to sustain the data processing and R&D needed to develop the second-generation system. Responsibility for the planning and coordination is an essential element, and should be assigned early. In this as in the early system, common elements among the disciplines should be stressed.

Space applications are further advanced in meteorology than in other fields. The sensors, data use and interpretation, and organization are also ahead. There probably are few common features with other disciplines. Direct quantitative inputs for mathematical models are needed in the interests of numerical weather prediction. For this purpose, large, high-speed electronic computers are available, and several techniques for securing the data from geosynchronous as well as low-altitude, polar-orbiting satellites seem promising.

*Recommendation*

NASA should continue to support and expand its space-technology programs aimed at securing the quantitative, world-wide, general-circulation atmospheric information required by the meteorological community for mathematical models of the world weather system.

The geosynchronous meteorological satellite is a more effective platform than it was first considered to be because resolution is higher, and the constant surveillance of the weather of a large part of the globe permits observation of the growth of storms, measurement of winds through the motion of clouds used as tracers, and vertical temperature sounding through cloud openings. Further, we can concentrate observation at high resolution in time and space on areas of rapidly developing mesoscale weather.

*Recommendation*

NASA and ESSA should continue to exploit this usefulness, leading toward capability for full tests by 1971. To permit rapid video playback in near-real time for warning, additional read-out capabilities and specialized display equipment may be required.

At present, more than 14,000 small data-collection platforms (for meteorology, oceanography, hydrology, and related disciplines) are operating around the world; the number is expected to reach 26,000 by 1975. Only restricted synoptic, real-time, data-collection service from these data platforms now exists. It is important that all the data be collected on a timely schedule, and a satellite system is substantially less costly than the conventional means of doing so.

*Recommendation*

Develop and deploy operationally a data-collection relay satellite system, to provide for the interrogation and collection of data from large numbers and types of widely distributed data platforms, such as hydrologic gauges, meteorological balloons, oceanographic buoys, and other sensors, and for the relaying of those data to specified data-processing centers.

Real-time readout of imagery direct from satellites to ground stations can be accomplished when such a system is needed. However, if this is not desired, or if read-out is required at a particular ground station, on-board storage must be provided. The necessary on-board, wide-band, long-lived data-storage and transmission equipment is beyond the present state of the art.

*Recommendation*

Undertake development of the necessary space-qualified wide-band recording and transmission equipment.

While real-time relay of imagery data from low-orbiting satellites is technically feasible, it does not appear cost-effective compared to direct readout from satellites to ground stations. Operational and cost advantages might, however, be realized if data-collection relay satellites could be used to replace the present NASA ground-tracking-station net.

*Recommendation*

We recommend that an early determination be made of operational and cost advantages realizable from the ongoing NASA Data Relay Satellite System program if, among other uses, the system replaces the NASA ground-tracking net. Pending the outcome, this program should continue with system definition and technology development.

## COMMUNICATION AND NAVIGATION

Broadcast by satellites is technically feasible from low-power satellites with large ground stations for transmission and/or rebroadcast, to high-power satellites with direct broadcast into homes.

*Recommendation*

Of all the uses we find for the different classes of broadcast satellites, two seem so easy technically, so reasonable economically, and so potentially desirable that we recommend consideration of their implementation by the proper authorities as a matter of high priority. One is a multi-channel distribution system for the use of network television transmission for both the private and public sectors of the industry. The other is a multi-channel system of the "teleclub" type for educational, instructional, and informational television for developing countries, as well as for those audiences sparsely spread throughout the United States, who require and need programming suited to their special interests—e.g., physicians, lawyers, engineers, educators.

A satellite system for navigation and traffic control over the North Atlantic would be likely to pay its way for shipping alone, provided all shipping were included. It would also provide for aircraft.

*Recommendation*

Immediately undertake efforts to design a system, identify the necessary operating organizations, and start the necessary R&D for establishment of a North Atlantic satellite navigation and traffic-control system to provide en route traffic control of transoceanic aircraft, traffic control of surface vessels in confluence areas, and improved search and rescue operations at sea.

## FREQUENCY UTILIZATION

The increasing use of satellites will, we anticipate, necessitate very large allocations in the radio-frequency spectrum. To accomplish this, effective long-range plans for management of the RF spectrum must be formulated and implemented which, because this will require considerable time, calls for immediate action.

*Recommendation*

The United States Government should promptly identify or create the authority to manage the total U.S. use of the radio-frequency spectrum, and then should man and fund the management operation adequately. The government and other appropriate responsible groups should also work toward increasing effectiveness of international agencies that are responsible for reaching agreements in radio-frequency management.

The availability of assignments in the radio-frequency spectrum will pace the entire scope of satellite applications.

*Recommendations*

Immediate consideration should be given, and required action taken, by the Federal Communications Commission and the International Telecommunication Union, to initiating the frequency-allocation process in order to secure frequency assignments within the following bands:

1) 108 MHz for FM broadcast
2) 470-890 MHz for direct-to-home broadcast (possibly restricted to the upper end of the band)
3) 2500-MHz band for educational television and other television services
4) 12,000 MHz for distribution service
5) Allocations in the 18-GHz and 35-GHz bands which may have important future uses

Allocate clear channels* wherever possible, especially in the UHF band.

## ORBITAL SPACING

Crowding of the geosynchronous orbit, causing radio-frequency interference, especially at continent-bisecting longitudes, may require international agreement for positions in the geosynchronous orbit.

*A clear channel, for the purposes of satellite broadcasting of television, is a channel that is free from interfering signals of sufficient magnitude to cause degradation of signal receptions on either a regional or local basis. Within the United States, where the desired frequency spectrum is already allocated to television broadcasting, clear-channel allocation would require that no conventional terrestrial broadcast station be licensed to broadcast on the clear-channel frequency allocation in such a way as to interfere with the satellite service.

*Recommendation*

The likelihood of crowding the geosynchronous orbit should receive definitive study, and when and if necessary, appropriate U.S. and international agencies should be created or identified, and adequately manned and funded for this purpose.

The use of satellites for point-to-point communication has only begun to fulfill its technical promise. Moreover, communication satellites will be concentrated in those arcs of the geosynchronous orbit that best serve the needs of intercontinental and domestic systems. This will necessitate minimum angular separation between adjacent satellites without creating radio-frequency interference, and probably lead to international agreements among the parties concerned regarding location and spacing of satellites, based on agreed technical parameters.

*Recommendation*

Research should be immediately undertaken to evaluate orbit-utilization principles as a basis for identifying available orbit space and the effect on orbit-spacing of modulation methods, frequencies, and related matters. In support of this, we recommend development of millimeter-wave technology, as well as multi-beam technology for satellites, inter-satellite relays, and system studies relating to overall point-to-point systems, their traffic aspects, break-even factors, frequency-sharing constraints, etc.

In our deliberations we have relied heavily on the Panel Reports. These volumes (listed below), which are available separately, contain much of the supporting documentation for our conclusions and recommendations.

Panel Report 1: Forestry-Agriculture-Geography
Panel Report 2: Geology
Panel Report 3: Hydrology
Panel Report 4: Meteorology
Panel Report 5: Oceanography
Panel Report 6: Sensors and Data Systems
Panel Report 7: Points-to-Point Communications
Panel Report 8: Systems for Remote-Sensing Information and Distribution
Panel Report 9: Point-to-Point Communications
Panel Report 10: Broadcasting
Panel Report 11: Navigation and Traffic Control

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* * * *

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