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National Aeronautics and Space Administration

Office of Space Science and Applications

Launch Vehicle and Propulsion Programs

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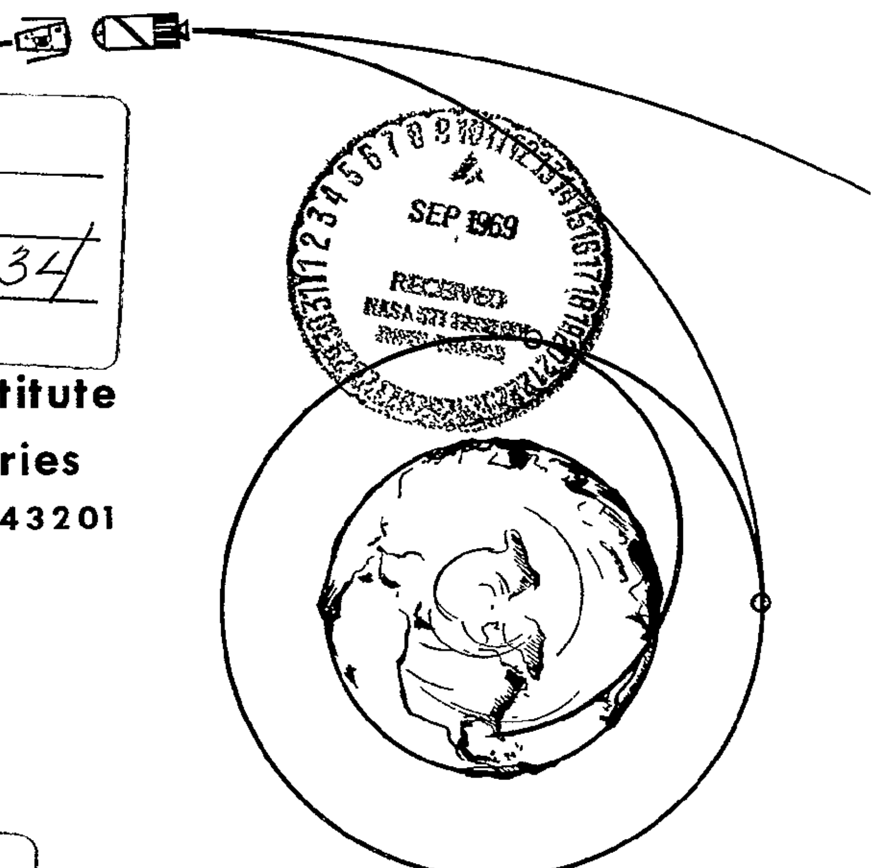

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ON
SELECTED SPACE GOALS AND OBJECTIVES
AND THEIR RELATION TO NATIONAL GOALS
TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
UNDER
CONTRACT NUMBER NASw-1146
PRINCIPAL INVESTIGATORS
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STATEMENT OF ATTRIBUTION AND DISCLAIMER

PREFACE

Why should Launch Vehicle and Propulsion Programs concern itself with examining the relationships between space goals and national goals?

There is continuing competition for the limited supply of federal budget resources and research and development capabilities. The future space program and the number and kind of launch vehicles that it will require can be reasonably judged only in the context of the overall competition for federal support.

NASA, like any federal agency, is one component in the totality of government operations. Its future plans must be formulated to enhance effectively the satisfaction of overall goals of the government. Studies such as this are designed to contribute to this purpose.

Further, launch vehicles are required for programs supporting an ever growing number of national purposes other than space. Examples of these programs include communications, weather forecasting, and earth resources surveys. By examining the relevancies of space goals, objectives, and activities to national functional goals, we expect to achieve more complete space transportation system planning based on a better understanding of the likely future.

This work was neither an attempt to justify a space program in terms of national goals nor an attempt to construct a space program designed specifically to support national goals. The work did involve an attempt to relate space goals to national goals so that subsequent efforts might yield predictions of the likely level of national support for various space program possibilities.

This report documents the second step in an effort to develop an improved rationale for use in long-range space transportation system planning. It identifies a useful set of goals and objectives in nine selected space program areas and subjectively assesses the relevance of these to national functional goals. The overall effort and this document are only elements in market research activities by space transportation system planners. This document should not be used out of context as an authoritative source of data on possible future space missions. Readers are directed to officials responsible for the various space program areas for such data. The results of this work are being published because there may be some general interest in the idea of subjective measurements of relevancies of goals and objectives in selected program areas to national functional goals.

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CHAPTER I

INTRODUCTION

N. A. Frazier and G. E. Wukelic

Background

This study is one of a series of tasks designed to improve the rationale used in long-range planning of space transportation systems. The overall effort is based on the premise that there exists,or should exist, meaningful relationships between national goals and priorities, and space goals and objectives. In turn, these relations can provide the basis for formulating a methodology for defining and analyzing rational future mission models required for national space transportation systems planning. This rationale hinges upon the ability to identify satisfactorily and then determine meaningful relationships between the two components: (1) national goals (and related priorities); and (2) space goals and objectives.

In a companion report,[1*] the following set of 13 national goals (or functions) was identified, described and functionally defined based on past and present allocations of Federal budget resources:

National Security	Labor and Manpower
Welfare	Veterans
Health	Space
Commerce, Transportation, and Communications	Housing and Community Development
Education and Knowledge	Natural Resources and Environment
Agriculture	
International Relations	General Government.

Funding allocations to these national goals (or functions) provide a yardstick for measuring priorities among the goals. These quantified relationships are indicators of the nation's willingness to commit funds for translating broad philosophical statements of national purpose into accomplishments. As such, these relationships may then be considered to be a meaningful measure of response to desires and purposes of the nation.

The study reported here was directed toward item (2) above, i.e., identifying a working set of space goals and objectives and attempting to determine relationships between them and the set of national goals. A subsequent study is expected to draw upon the results of these two preliminary steps and attempt to develop methodologies for generating realistic space program plans based on the relationship of space goals to national goals and the apparent willingness of the nation to commit funds to those goals. These realistic long-range space program plans are a necessity for long-range planning of space transportation systems because they define the number and kind of launch vehicles that may be required and when they will be needed.

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* Superscripts denote references cited at the end of this chapter.

A single generally accepted long-range NASA plan does not exist. Further, about half of the future automated space launches for which NASA is responsible are expected to be for non-NASA missions. These include missions for other government agencies, commercial organizations such as Comsat, foreign countries and international organizations. Long-range planning of the space transportation system, therefore, requires extensive "market survey" activity by launch vehicle planners to define the "job".

Perspective of the Study

This study encompasses a broad, but not exhaustive, spectrum of NASA interests and activities. In addition, selected space interests or activities of other organizations (including the Department of Defense, Department of Interior, National Science Foundation, Atomic Energy Commission, Department of Commerce, Department of Transportation, National Academy of Sciences, National Aeronautics and Space Council, Comsat, and others) were also considered to some extent.

Space topics examined are as follows:

Space Physics	Earth Resources Satellites
Space Astronomy	Meteorological Satellites
Planetary Exploration	Geodetic Satellites
Space Biology	Navigation and Traffic Control Satellites.
Communications Satellites	

Space goals and objectives set forth in the literature were reviewed. The majority of the literature was either NASA-originated or resulted from NASA-funded studies. Of particular value were the NASA Office of Space Science and Applications Prospectus and Program Memoranda, the National Academy of Science's Space Science Board and the President's Science Advisory Committee reports, and documentation prepared in defense of the NASA budget. Numerous NASA-contracted reports and specialized technical publications were utilized where appropriate.

The literature reveals that the status of planning for various space program areas vary considerably, with some in quite early stages of development of program concepts. They are all subject to change. A reasonable effort was made to use the most up-to-date and authorative program descriptions, but the reader is cautioned not to use these descriptions, out of context. If he requires official space program planning data, he should approach those officials directly responsible for those programs.

In performing this study, individual project staff members had the option of using the published goals and objectives or formulating a working set patterned after those published. All contributing authors exercised the latter option to varying degrees. In general, it was convenient, for space transportation considerations, to formulate what amounted to functional or topical objective categories and to relate these levels of activity to national goals. In no case during this preliminary study were individual mission objectives assessed.

Study Approach

At the heart of the rationale under examination is the use of simple table matrices that numerically link space program area goals and objectives to each of the 13 national goals noted previously. Preparation of these matrices has been attempted here on a trial basis using a numerical scale between 0 and 5, inclusive, to show the relevancy of a space objective to a national goal. For this purpose, space programs are represented by objectives which are to result in products, services, and/or knowledge applicable to national goals. The time when these products, services, and/or knowledge become available is influenced by funding levels and scientific and technical capabilities. The relevancy numbers, in concept, represent only a subjective estimate of their national utility.

In setting up the relevancy scale the following simple considerations applied:

5 - <u>Critically relevant</u>. Products, services, and/or knowledge implicit in space objectives are unique and necessary to satisfaction of needs associated with the national goal.

4 - <u>Fundamentally relevant</u>. Products, services and/or knowledge developed are of the type fundamental (but not critical) to fulfilling needs associated with the national goal.

3 - <u>Advantageously relevant</u>. Products, services, and/or knowledge are of the type that upgrades the ability to satisfy needs associated with the national goal although, in their absence, the needs could still be satisfied.

2 - <u>Conveniently relevant</u>. Products, services, and/or knowledge are of the type that will be used when available in a supporting manner.

1 - <u>Remotely relevant</u>. Availability or absence of products, services, and/or knowledge is of little consequence.

0 - <u>No apparent relevancy</u>.

Throughout this study, caution has been the watchword because of the difficult, delicate, and argumentative nature of any assessment, whatever its purpose, of the potential "value" or application of research oriented endeavors. The sophistication and detail of most publicized assessment and planning methodologies scanned in this study[2-9] go far beyond that envisioned for a workable "National Priorities Planning Rationale", the latter being more similar to the "Social Merit Matrix" rationale proposed by W. D. Carey of the Bureau of the Budget.[10-12] The overriding concern is to keep the rationale simple and if it proves to have any merits, one will be simplicity in its application. In that light, the relevancy numbers are nothing more than an attempt to quantify relationships that otherwise would take pages to describe (witness this report). This does not make the relevancy numbers, that are used herein to examine the rationale, correct; neither does it rule out the rationale on the basis of its present stage of investigation. However, the simplicity and status of the rationale does permit the reader to make his own relevancy estimates if he so desires. To be compatible with the approach of the writers, the reader, in his estimate, will need to consider past accomplishments in some cases, potential contributions in other cases, and a mixture of the proven and potential in still other cases. The reader is cautioned about making comparisons within and among program areas and further advised that this report is not a planning document in itself. It merely represents a status report on investigations of a basic planning premise.

Report Format

The complete report consists of 11 chapters. Chapter II contains an overview and summary of the preliminary findings. Each of the remaining nine chapters (III-XI) is devoted to a description of specific space efforts, the goals and objectives, and (on a trial basis) the relating of the associated activities and results to national goals. A matrix associating the broad space objective categories, for the program area being discussed with national goals precedes each of these nine chapters. A summary of funded, planned and/or proposed payload possibilities and associated launch features is also provided for each program area. Literature cited in each chapter is listed in the "References" at the end of that chapter.

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OVERVIEW AND SUMMARY

G. E. Wukelic and N. A. Frazier

Introduction

The purpose of this study was to establish a working set of space goals and objectives and to attempt to relate them to the previously established set of 13 national goals[1*] discussed in Chapter I. This chapter summarizes the results of these efforts and outlines a set of goals and objectives in 9 space science and application program areas along with subjective estimates of relevancies to the national goals. Broad interpretations of the resulting "relevancy matrices" are also given. The remaining chapters of this report (Chapters III-XI) provide the detailed documentation of the results summarized in this chapter.

The final section of this chapter presents some general comments concerning the status of the overall effort to develop the "National Priorities Planning Rationale" for space transportation system planning.

Space Goals and Objectives and Relevancies to National Goals

Since the establishment of NASA, numerous planning groups have contributed to the formulation of plans, goals, objectives, and priorities required for conducting an effective and viable U.S. space program. Most useful to this study have been the reports of the National Academy of Sciences' Space Science Board, the National Academy of Engineering, the President's Science Advisory Committee, the National Aeronautics and Space Council, as well as various NASA Planning Steering Groups and ad hoc working groups. Also, pertinent were statements and recommendations of the Space Science and Applications Steering Committee and its Advisory Subcommittees-comprised of members from the scientific community (university and NASA laboratories) as well as industrial and user oriented organizations.**

Published opinions and recommendations of these official planning panels and groups relative to space science and applications goals and objectives (particularly those of a more recent vintage[2-9]) served as the basis for this part of the analysis. However, because of the specific need to state and structure space goals and objectives so as to be most revealing in terms of launch vehicle requirements, some restatement and restructuring of publicized goals and objectives were required. Further, attempts were made to adopt broad goals and objectives which would be least sensitive to changing national and international attitudes and developments.

The National Aeronautics and Space Act of 1958 contains the official declaration of policy and purpose of the U.S. space program. Selected portions of this Act are cited below because this legislation continues to provide the basic guidelines and bounding constraints for the U.S. space program:

- ...it is the policy of the United States that activities in space should be devoted to peaceful purposes for the benefit of all mankind.

* Superscripts denote references cited at the end of this chapter.
** References to the items discussed in this paragraph are contained in the technical Chapters (III-XI).

- ...the general welfare and security of the United States requires that adequate provision be made for aeronautical and space activities.
- The aeronautical and space activities of the United States shall be conducted so as to contribute materially to one or more of the following:

  (1) The expansion of human knowledge of phenomena in the atmosphere and space.

  (2) The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles.

  (3) The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space.

  (4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes.

  (5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere.

  (6) The making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control non-military aeronautical and space activities, of information as to discoveries which have value or significance to that agency.

  (7) Cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results thereof.

  (8) The most effective utilization of the scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment.

In addition to the Space Act, NASA programs and activities fall within the broad space goals designated by the Bureau of the Budget[10] as well as those established by NASA itself:[2-9] These goals, rephrased in some instances, follow:

- Space goals described in the Budget[10] prescribe programs designed to:

  (1) Improve our ability to operate in the space environment

  (2) Advance man's knowledge of the universe

  (3) Use the experience gained for man's benefit.

- NASA publicized goals are for:
  - Space sciences[2-8] to
    (1) Master the near-Earth (terrestrial) space environment
    (2) Explore the solar system
    (3) Improve understanding of the universe.
  - Space applications[2-9] to
    (1) Recognize and respond to the needs of society by appropriate research and development and flight test of experiments, subsystems, and spacecraft in areas of space applications technology.

Although these statements are useful in relating various space activities to space--which is one of the 13 functional national goals[1], they are too generalized to be of much value in establishing specific relationships between space goals and objectives and the remaining national goals. It is only feasible to relate space goals and objectives to national goals through consideration of the subprogram functional objectives and related topical objectives (or activities) for each of the major space program areas.

The national utility of the space program is a topic of increasing political and public concern. Congress has requested, and is periodically receiving, status reports on the practical results accruing from our national space investment.[11] In addition, numerous luncheon speeches, press editorials, and to a lesser extent, technical documents and articles have examined this topic. A recent study of the benefits of the space program conducted by Stanford Research Institute[12] identifies over 200 references as being applicable to the subject of "Benefits of the U.S. Space Program".

In the following pages, an overview of the goals, broad objectives, subprogram (functional) areas, and topical (objective) activities are discussed and associated with the national goals for nine selected NASA space program areas. The association with national goals is presented in terms of the relevancy matrices from each of the technical chapters where the documentation of the basis for the material displayed here for Space Science (i.e., physics, astronomy, planetary exploration, and biology) are given in Chapters III-VI and those for space applications (i.e., communications, Earth resources, meteorological, geodetic, and navigation and traffic control satellites) are given in Chapters VII-XI. Emphasis was placed on identifying the more explicit and most direct associations between space and national activities and interests. Less meaningful associations, such as those considered to be routine or nominal in nature, were generally excluded. For long well-established space activities, known examples of past applications formed the basis for the association claim. Potential applications were considered sufficient justification for claiming association for the more recently established space objectives. A discussion of the 0 through 5 relevancy ratings was presented in Chapter I.

Space Physics

The basic goals of the space physics program are to:

- Improve understanding of the nature of the space environment and the interactions and dynamic processes which control it
- Explore new regions of space
- Exploit space as a laboratory.

In order to achieve these goals, activities in the following subprogram areas with related broad objectives are being pursued:

Subprogram Functional Areas	Broad Objectives
Near-Earth (terrestrial) space	To develop the ability to understand, forecast, utilize, protect, and modify the near-Earth space environment
Interplanetary and galactic space	To understand the nature and variability of solar wind, solar and intergalactic magnetic fields and cosmic radiation, and interplanetary dust
Space as a laboratory	To perform automated and man-assisted physics experiments in space.

Table II-1, on the right, presents the association and preliminary estimates of numerical relevancies of space physics activities to national goals. As is shown, space physics can be related to 5 of the 13 national functional goals. The highest relevancies are associated with education and knowledge, and (for some activities) with national security and space. Particles and fields, and ionospheric physics appear to have the highest relevancy to a broader spectrum of national goals.

TABLE II-1. ESTIMATE OF THE RELEVANCY OF SPACE PHYSICS OBJECTIVES TO NATIONAL GOALS

Subprogram Functional Areas	Topical Objective Activities	National (Functional) Goals: National Security	Education and Knowledge	Space	International Relations	Natural Resources and Environment
Near-Earth (Terrestrial) Space						
	Atmospheric Structure and Composition	4	4	4	3	3
	Ionospheric Physics	5	4	4	3	4
	Particles and Fields	5	4	5	3	4
	Solar Physics (see Space Astronomy Chapter)					
Interplanetary and Galactic Space						
	Particles and Fields	3	4	5	3	4
	Interplanetary Dust	1	3	4	1	1
Space as a Laboratory						
	Relativistic Mechanics	2	5	2	1	2
	High Energy Physics	3	5	3	1	0
	Controlled Geophysical Experiments	5	5	3	3	4
	Spacecraft-Environment Interactions	5	3	4	0	2
	In-Space Behavior of Matter	3	4	4	1	0
	Plasma Physics	2	4	3	1	3
	Manned Experiments	3	3	4	1	0

RELEVANCY RATING:

5	Critically Relevant	2	Conveniently Relevant
4	Fundamentally Relevant	1	Remotely Relevant
3	Advantageously Relevant	0	No Apparent Relevancy

Space Astronomy

The basic goal of the space astronomy program is to:

- Undertake astronomical observations in space in support of Earth-bound astronomical efforts to understand the origin, evolution, present structure, behavior, and ultimate destiny of the Sun, the solar system, and the universe.

In order to achieve this goal, activities in the following subprogram areas with related broad objectives are being pursued:

Subprogram Functional Areas	Broad Objectives
Automated astronomical observatories	To develop and utilize automated satellites for conducting astronomical investigations in all regions of the electromagnetic spectrum
Man-associated astronomical observatories	To utilize the unique capabilities of man to support and perform space astronomical observations
Ground-based astronomical activities	To complement space astronomy investigations with appropriate ground-based research.

Table II-2, on the right, presents the association and preliminary estimates of numerical relevancies of space astronomy activities to national goals. As is shown, space astronomy can be related to 5 of the 13 national functional goals. The highest relevancies are associated with education and knowledge, and (for some activities) with national security and space. As might be expected, solar astronomy with the automated astronomical observatories has the highest relevancies for a broad spectrum of national goals.

TABLE II-2. ESTIMATE OF THE RELEVANCY OF SPACE ASTRONOMY OBJECTIVES TO NATIONAL GOALS

Subprogram Functional Areas	Topical Objective Activities	National (Functional) Goals				
		National Security	Education and Knowledge	Space	International Relations	Natural Resources and Environment
Automated Astronomical Observations	Solar Astronomy	5	4	5	4	4
	Stellar Astronomy	3	5	4	3	0
	Planetary Astronomy[a]					
	High-Energy Astronomy	3	5	4	3	3
	Radio Astronomy	3	5	4	3	2
	Infrared Astronomy	5	5	4	3	1
Man-Associated Astronomical Observations	Solar Astronomy	2	2	2	3	2
	Stellar Astronomy	2	2	2	3	0
	High-Energy Astronomy	2	2	2	3	1
	Other (Radio, Infrared, etc.)/NASO	4	4	4	4	4
Ground-Based Astronomical Activities	All Disciplines	Not Applicable--No Launch Vehicle Requirements				

(a) See Planetary Exploration chapter.

RELEVANCY RATING:

5 Critically Relevant	2 Conveniently Relevant
4 Fundamentally Relevant	1 Remotely Relevant
3 Advantageously Relevant	0 No Apparent Relevancy

Planetary Exploration

The basic goals of the planetary exploration program are to improve the understanding of:

(1) The origin and evolution of the solar system

(2) The origin and evolution of life

(3) The dynamic processes that shape the terrestrial environment.

In order to achieve these goals, activities in the following subprogram areas with related broad objectives are being pursued:

Subprogram Functional Areas	Broad Objectives
Earth-based planetary exploration	To observe the planets from the surface of the Earth by all means that present-day technology can provide
Near-Earth planetary exploration	To observe the planets from balloons, rockets, and automated and manned satellites
Automated planetary exploration	To observe the planets using automated flybys, orbiters, or landers
Manned planetary exploration	To undertake manned missions to the planets.

Table II-3, on the right, presents the association and preliminary estimates of numerical relevancies of planetary exploration activities to national goals. As is shown, planetary exploration can be related to 6 of the 13 national functional goals; however, only the relevancies to education and knowledge, space, and international affairs can be considered significant. It would appear that, as in the past, Mars and Venus automated missions have the highest relevancies to a broad spectrum of national goals.

TABLE II-3. ESTIMATE OF THE RELEVANCY OF PLANETARY EXPLORATION OBJECTIVES TO NATIONAL GOALS

Subprogram Functional Areas	Topical Objective Activities	National (Functional) Goals: Education and Knowledge	Space	International Relations	Health	Natural Resources and Environment	Agriculture
Earth-Based	All Planets	Not Applicable--No Launch Vehicles Involved					
Near-Earth	All Planets	3	3	3	0	0	0
Automated	Mars	4	5	4	3	2	3
	Venus	4	5	4	1	2	1
	Mercury	5	4	3	1	2	1
	Jupiter	4	5	3	1	2	0
	Other Planets	4	5	3	1	2	0
	Comets and Asteroids	5	3	3	0	0	0
Manned[(a)]	Mars-Venus	4	5	3	1	0	1

(a) No formal program in existence.

RELEVANCY RATING:

5 Critically Relevant
4 Fundamentally Relevant
3 Advantageously Relevant
2 Conveniently Relevant
1 Remotely Relevant
0 No Apparent Relevancy

Space Biology

The basic goals of the space biology program are to:

- Gain new fundamental biological knowledge by using space flight as a research tool
- Develop a fundamental, coherent, and unifying biological theory of life, incorporating the important role played by gravity and time in life processes and structure.

In order to achieve these goals, activities in the following subprogram areas with related broad objectives are being pursued:

Subprogram Functional Areas	Broad Objectives
Effect of space on living organisms (including man)	To determine the effects of the space environment on Earth organisms, including man
	To accomplish research and space flight missions to discover anything unique in the space environment which is pertinent to life in space
Extraterrestrial life	To determine the location, origin, nature, and level of development of extraterrestrial life
Long-duration manned space flights	To develop information in support of long-duration manned space flight.

Table II-4, on the right, presents the association and preliminary estimates of numerical relevancies of space biology activities to national goals. As is shown, space biology can be related to 7 of the 13 national functional goals; however, to one of these the relevance is only that of convenience. The highest relevance ratings are associated with those aspects of the biology program which may contribute to the eventual development of a unifying theory of life.

TABLE II-4. ESTIMATE OF THE RELEVANCY OF SPACE BIOLOGY OBJECTIVES TO NATIONAL GOALS

Subprogram Functional Areas	Topical Objective Activities	National (Functional) Goals: National Security	Education & Knowledge	Commerce Transportation Communications,	Agriculture	Space	Health	International Relations
Effect of Space on Living Organisms (including man)	Weightlessness	4	3	2	2	5	3	2
	Biorhythms	4	5	2	4	5	3	4
	Radiation	4	3	2	2	5	3	4
Extraterrestrial Life	Theories and Model Development	0	5	0	2	2	4	4
	Detection	0	3	0	2	5	2	3
	Recognition	0	3	0	2	5	2	3
Long-Duration Manned Space Flights	Understand Gravity Effects	4	3	2	0	5	2	2
	Study Known Effects Such as Bone Demineralization	4	3	2	0	5	3	2
	Effects of Acceleration on Fat Deposition	4	3	2	0	5	3	2
	Why Hypothermia Protects Against Radiation	4	3	2	0	5	3	0
	Why Bacteria Grow in Unnatural Environments	3	2	2	0	5	3	0
	Eye Movements During Sleep	2	2	2	0	4	2	0
	Sensorimotor Coordination in Space	3	2	2	0	4	2	0

Relevancy Rating:
- 5 Critically Relevant
- 4 Fundamentally Relevant
- 3 Advantageously Relevant
- 2 Conveniently Relevent
- 1 Remotely Relevant
- 0 No Apparent Relevancy

Communications Satellites

The basic goals in communications satellites are to:

- Study requirements for and technically assess the applicability of satellites to meet future communications needs
- Ensure that new technology is available when needed
- Fulfill responsibilities assigned to NASA in the Communications Satellite Act of 1962.

In order to achieve these goals, subprograms in point-to-point and broadcast communications have been initiated. To assure success in these applications, the following broad objectives are being pursued:

- Understand, on a statistical basis, the effects of the atmosphere on the propagation of electromagnetic waves, above 10 GHz, through the medium
- Promote the more efficient use of the electromagnetic spectrum through the employment of optimum modulation techniques, signal processing methods, and frequency sharing
- Develop and demonstrate multiple access communications techniques for use with ever increasing numbers of small, low cost fixed and mobile users
- Develop and demonstrate space technology for precision pointing of single and multiple beams from stabilized platforms in the geostationary orbit for application to space broadcasting and data relay and real-time tracking and command capability.

Table II-5, on the right, presents the association and preliminary estimates of numerical relevancies of communications satellite activities to national goals. As is shown, communications satellite activities can be related to 6 of the 13 national functional goals. The highest relevancies are those between point-to-point communications and national security and between small user point-to-point communications and commerce, transportation and communications. There is a continuing fundamental relevancy to space because of past and potential future contributions to satisfying Space and Communications Satellite Act goals. In addition, future communications satellites may be fundamental for relaying messages from space vehicles.

TABLE II-5. ESTIMATE OF RELEVANCY OF COMMUNICATIONS SATELLITES OBJECTIVES TO NATIONAL GOALS

Subprogram Functional Areas	Topical Objective Activities	National (Functional) Goals: National Security	International Relations	Commerce, Transportation and Communications	Education and Knowledge	General Government	Space
Point-to-point Communications	Large User (fixed)	5	4	3	1	4	4
	Small User (multiple access-mobile)	5	4	5	1	5	4
Broadcast	Voice (small user)	1	3	1	3	3	4
	TV to broadcast center	1	3	1	3	3	4
	TV to modified receiver	1	3	1	3	3	4
	TV to unmodified receiver	1	4	2	3	3	4

Relevancy Rating:

5 Critically Relevant
4 Fundamentally Relevant
3 Adventageously Relevant
2 Conveniently Relevant
1 Remotely Relevant
0 No Apparent Relevancy

Earth Resources Survey Satellites

The basic goal in Earth resources survey programs (ERSP) is to:

- Contribute to the understanding and management of Earth resources of economic, social, and cultural interest

In order to achieve this goal, subprogram activities related to oceanography, agriculture, geography and cartography, hydrology, and geology have been initiated. For these purposes, the following broad objectives are being pursued:

- Determine and assess the role of space technology for improving the exploration, development, and utilization of Earth resources

- Apply existing and develop necessary technology to conduct Earth resource surveys from space

Table II-6, on the right, presents the association and preliminary estimates of numerical relevances to national goals. As is shown, ERSP activities can be related to 10 of the 13 national functional goals. The highest relevancies are associated with space because of the clear relationships to space act goals; however, the relevancies to agriculture and to natural resources and environment are certainly significant. Although these ERSP activities are also expected to contribute to national security, and international affairs, the relevancy to the other 5 national goals must be considered weak.

TABLE II-6. RELEVANCY OF ERSP TOPICS TO NATIONAL GOALS

SUBPROGRAM FUNCTIONAL AREAS	TOPICAL OBJECTIVE ACTIVITIES	NATIONAL (FUNCTIONAL) GOALS: NATIONAL SECURITY	INTERNATIONAL RELATIONS	SPACE	AGRICULTURE	NATURAL RESOURCES AND ENVIRONMENT	COMMERCE, TRANSPORTATION, AND COMMUNICATIONS	HOUSING AND COMMUNITY DEVELOPMENT	HEALTH	EDUCATION AND KNOWLEDGE	GENERAL GOVERNMENT
OCEANOGRAPHY	Environmental description, Forecasting - Control	4	3	5	1	4	1	0	1	4	1
	Environmental quality	0	2	3	0	3	1	0	1	1	1
	Food	1	3	5	1	4	0	0	1	1	1
	Coastal engineering	2	1	3	0	2	1	0	0	1	1
	Structures, engineering design	2	1	3	0	2	1	0	0	1	1
	Transportation	3	3	4	1	3	1	0	0	1	1
AGRICULTURE	Land conservation	1	3	3	3	3	0	0	0	1	1
	Land reclamation	1	3	3	3	3	0	0	0	1	1
	Irrigation planning	1	3	3	3	3	0	0	0	1	1
	Crop census	1	3	5	3	0	1	0	1	1	1
	Timber census	1	3	4	3	0	1	0	0	1	1
	Soil description	3	3	4	3	3	0	0	0	1	1
	Wild life census	1	2	3	0	2	0	0	0	1	1
	Crop yield estimates	1	3	4	4	0	1	0	1	1	1
	Crop stress detection	1	3	5	4	0	1	0	1	1	1
	Timber stress detection	1	3	4	4	0	1	0	0	1	1
GEOGRAPHY AND CARTOGRAPHY	Environmental description	3	3	4	3	4	1	0	0	2	1
	Land use, planning, changes	1	3	4	3	3	1	1	0	1	1
	Transportation	2	2	3	1	3	1	0	0	1	1
HYDROLOGY	Environmental forecasting - control	3	3	4	3	4	1	0	0	2	1
	Environmental quality	0	2	3	0	3	0	0	1	1	1
	Water resources	2	3	4	1	3	0	0	0	1	1
	Engineering	2	1	3	1	2	0	0	0	1	1
GEOLOGY	Environmental description, Forecasting - Control	3	3	4	2	4	1	0	0	2	1
	Petroleum, mineral resources	1	3	3	1	3	0	0	0	1	1
	Geothermal energy	1	2	2	0	2	0	0	0	1	1
	Engineering	2	1	3	1	2	1	0	0	1	1

RELEVANCY:

5 = Critically relevant
4 = Fundamentally relevant
3 = Advantageously relevant
2 = Conveniently relevant
1 = Remotely relevant
0 = No apparent relevancy

Meteorological Satellites

The basic goal in satellite meteorology is to:

- Contribute to the exploration, understanding, definition, and prediction of the structure and behavior of the atmosphere

To achieve this goal, the following broad objectives are being pursued:

- Understand the dynamics of the Earth's atmosphere including its response to external effects such as solar input, land-ocean distribution, and air-sea exchange processes
- Develop and demonstrate atmospheric vertical sounding techniques
- Improve temporal, spatial and spectral resolution capability, as appropriate
- Develop the necessary space technology for the Global Atmospheric Research Program
- Establish a basis for experiments in weather modification and control.

In Table II-7, on the right, the various satellite orbital classes which can be used for the subprogram functional areas (i.e., severe weather monitoring, short period forecasting, extended period forecasting, and climatology) have been associated with the national functional goals. The preliminary estimates of relevancy numbers shown illustrate that the orbit selection can significantly affect the degree to which needs associated with national goals can be satisfied. As is shown, meteorological satellite activities can be related to 9 of the 13 national functional goals. The highest relevancies are associated with national security and satisfaction of Space Act goals; however, the associations with international affairs, with natural resources and environment, and with commerce, transportation and communications are certainly significant.

TABLE II-7. ESTIMATE OF RELEVANCY OF SATELLITE METEOROLOGY TO NATIONAL GOALS

Subprogram Functional Areas	Topical Objective Activities (Orbital Classes)	National (Functional) Goals: National Security	International Relations	Space	Agriculture	Natural Resources and Environment	Commerce, Transportation, and Communications	Health	Education and Knowledge	Government
Severe Weather Monitoring Short Period Forecasting Extended Period Forecasting Climatology	Near-Earth Sun-synchronous	5	4	5	3	3	4	3	3	3
	Geosynchronous	5	3	5	3	3	4	1	3	3
	Near-Earth equatorial	3	2	3	1	1	3	1	3	2
	Manned, various orbits or maneuverable	2	2	2	2	2	2	2	3	2

Relevancy Rating:

5 Critically relevant
4 Fundamentally relevant
3 Advantageously relevant
2 Conveniently relevant
1 Remotely relevant
0 No relevancy

Geodetic Satellites

The basic goal for satellite geodesy is to:

- Determine the Earth's size and shape, surface geometry, and dynamics and apply this knowledge to practical situations

To achieve this goal, the following subprogram functional areas and related broad objectives are being pursued:

Subprogram Functional Areas	Broad Objectives
Geometric Geodesy	To establish a unified world reference system
Gravimetric Geodesy	To provide a refined description of the Earth's gravitational field
Applications Support	To apply geodetic satellite technology to Earth and space sciences

Table II-8, on the right, presents the association and preliminary estimates of numerical relevancies of these geodesy subprogram functional areas (and related topical objective activities) to national functional goals. As is shown, these geodesy activities can be associated with 8 of the 13 national goals; however, the relevancies to agriculture, commerce, and community development are comparatively weak. As might be expected, the strongest associations are with national security. Geometric geodesy activities appear to have stronger relevancies to a broader spectrum of national goals than do the other activities.

TABLE II-8. ESTIMATE OF RELEVANCY OF SATELLITE GEODESY OBJECTIVES TO NATIONAL GOALS

SUBPROGRAM FUNCTIONAL AREAS	TOPICAL OBJECTIVE ACTIVITIES	NATIONAL (FUNCTIONAL) GOALS							
		NATIONAL SECURITY	SPACE	EDUCATION AND KNOWLEDGE	INTERNATIONAL RELATIONS	NATURAL RESOURCES AND ENVIRONMENT	COMMERCE, TRANSPORTATION AND COMMUNICATIONS	AGRICULTURE	HOUSING AND COMMUNITY DEVELOPMENT
GEOMETRIC GEODESY	Datum Connection	5	5	4	3	0	0	0	0
	Control Point Locations	3	4	3	1	3	2	2	3
	Marine Control Point Locations	5	5	4	3	3	1	2	1
	Island and Inaccessible Areas Connection	5	5	1	1	2	0	0	1
	Fiducial Points Location	3	3	1	1	4	3	3	4
GRAVIMETRIC GEODESY	Harmonic Coefficient of Gravity Field	4	4	4	0	0	0	0	0
	Gravity Anomaly Location	3	2	3	0	3	0	1	0
	Orbit Precision Determination	4	5	4	1	0	2	1	3
APPLICATION SUPPORT	Marine Geodesy/ Precise Ship Positioning	4	4	4	3	3	2	3	1
	Oceanography/ Satellite altimetry	4	4	4	3	3	2	3	0
	Solid-Earth Geophysics	2	4	4	2	3	1	3	1
	Space Sciences	4	4	4	4	3	1	0	0

Relevancy Rating:

5 Critically Relevant
4 Fundamentally Relevant
3 Advantageously Relevant
2
2 Conveniently Relevant
1 Remotely Relevant
0 No Apparent Relevancy

Navigation and Traffic Control Satellites

The basic goal of navigation and traffic control programs is to:

- Contribute to the improvement of transocean travel by air and sea vehicles by providing an improved means of navigation and position fixing, and, through a means of data transfer, help improve traffic control and search and rescue aids

To achieve this goal, the following broad objectives (related primarily to sea and air transport--but possibly to land transportation also) are being pursued:

- Provide experimental satellite navigation data to the user community by which they can evaluate their utility to meet their needs

- Conduct satellite systems studies which provide information on spacecraft, ground station and user hardware configurations and costs

- Evaluate promising navigation satellite techniques to meet the future needs of the aviation and marine community

Table II-9, on the right, presents the association and preliminary estimates of numerical relevancies of the navigation and traffic control program activities with national functional goals. As is shown, these activities can be related to 7 of the 13 national goals; however, the relevancy to agriculture appears to be insignificant. The highest relevancies are for search and rescue activities to commerce (air and sea), and international relations (sea), and for air traffic control to commerce and transportation. Land navigation relevancy numbers are comparitively insignificant. As might be expected, air traffic control and rescue activities are of principal interest; however, position determination may become critical later as transoceanic flights increase.

TABLE II-9. ESTIMATE OF RELEVANCY OF NAVIGATION AND TRAFFIC CONTROL SATELLITES TO NATIONAL GOALS

Subprogram Functional Areas	Topical Objective Activities	National (Functional) Goals: National Security	Commerce, Transportation, & Communications	Education & Knowledge	International Relations	Natural Resources & Environment	Space	Agriculture
Air Navigation	Position Determination	3	4	3	3	3	3	1
	Traffic Control	3	5	3	3	2	3	0
	Search and Rescue	4	5	2	3	2	4	0
	Data Collection/ Telemetry	3	4	2	3	3	2	1
Sea Navigation	Position Determination	3	3	2	3	4	4	2
	Traffic Control	2	4	1	3	2	3	0
	Search and Rescue	4	5	1	5	1	5	0
	Data Collection/ Telemetry	3	4	3	3	4	3	3
Land Navigation	Position Determination	3	2	1	1	3	1	1
	Traffic Control	2	3	1	1	1	1	1

Relevancy:

5 Critically relevant
4 Fundamentally relevant
3 Advantageously relevant
2 Conveniently relevant
1 Remotely relevant
0 No apparent relevancy

Broad Associations

As noted earlier, the relevancy ratings within each space program area (shown in the preceding pages) are subjective, but informed, judgements by the research team. Other individuals or groups would very likely assign different values. The most meaningful judgements should be those of the individuals and/or organizations responsible for the space program areas and for the national (functional) goals. If the judgement of the NASA manager on the contribution his program might make to a national goal coincided with that of "the national goal manager(s)", then these reinforcing estimates would justify a high level of confidence. In general, there is a NASA manager responsible for each space program area included in this study, but there is no recognized single manager for the national goals or related functional areas. A program manager's judgements might be expected to be subjective and optimistic as to the potential value of his projected activities. A national goal manager, if he existed, would tend to evaluate objectively all the alternatives available to him in working toward his goals. In a sense, the functions of the national goal manager(s) are now being performed by a combination of the President, the White House staff, the Bureau of the Budget, and Congress.

The relevancy ratings generated in this study are judged to have utility for space transportation system planning. In addition, they may have an intrinisic fundamental objective value since the authors were relatively well informed on these subjects and were not personally involved in the programs concerning which they were making judgements. The assumptions, methodology, and evaluations are presented and explained in the technical chapters (III-XI) so that readers may modify or redo all or part of the study with reasonable ease. Exact numerical relevancy ratings would vary among individuals making the ratings; however, there is not likely to be significant variations in the go, no-go judgements. In the overall methodology of the study, the numerical relevancy ratings are not crucial. They were primarily intended to communicate the author's judgements of weak or strong potential contribution.

Figure II-1 presents the resulting (broad) association matrix between the selected NASA space science and applications programs considered and national functional goals. As might be expected because of their applied nature, application programs exhibit a stronger association with national goals. The combined space science and applications programs considered were found to be relatable to 10 of the 13 national functional goals. Although no associations were claimed for the Welfare, Labor and Manpower, or Veterans functional field categories, all nine space program areas were considered to be associated in some manner with the three national goals of Education and Knowledge, International Relations, and Space.

Somewhat surprising was the finding that space science activities are or have the potential of contributing to 8 of the 13 national goals; the association being either nonexistent or nominal in the functional field categories of Welfare, Labor and Manpower, Housing and Community Development, Veterans, and General Government. The Space Biology Program was chiefly responsible for this broad association. All space science program areas were shown to be related to Education and Knowledge, Space, and International Relations, and with the exception of Planetary Exploration, to National Security as well.

Collectively, the applications program areas could be related to 10 of the 13 national goals with the exceptions being the Welfare, Veterans and the Labor and Manpower goals. Five of the national goals are or can be contributed to by all the application programs--National Security, Commerce, Transportation and Communications, Education and Knowledge, International Relations, and Space.

Space Program Areas	National Security	Welfare	Health	Commerce, Transportation, and Communications	Education and Knowledge	Agriculture	International Relations	Labor and Manpower	Veterans	Space	Housing and Community Development	Natural Resources and Environment	General Government
	National (Functional) Goals												
Space Physics	●				●		●			●		●	
Space Astronomy	●				●		●			●		●	
Planetary Exploration			●		●	●	●			●		●	
Space Biology	●		●	●	●	●	●			●			
Communications	●			●	●		●			●			●
Meteorology	●		●	●	●	●	●			●		●	●
Navigation & Traffic Control	●			●	●	●	●			●		●	
Earth Resource Surveys	●		●	●	●	●	●			●		●	●
Geodesy	●			●	●	●	●			●	●	●	

FIGURE II-1. ASSOCIATION OF SPACE GOALS, OBJECTIVES, AND ACTIVITIES TO NATIONAL GOALS IN SELECTED SPACE PROGRAM AREAS

General Observations on the Status of the "National Priorities Planning Rationale"

As stated in Chapter I, the basic premise of the "National Priorities Planning Rationale" is that "There exists, or should exist, meaningful relationships between national goals priorities, and space goals and objectives" which can be useful in space transportation system planning. The study of this stated premise has resulted in the following accomplishments:

(1) A set of space goals, objectives, and activities has been determined which can be correlated with a set of previously established national goals.[1]

(2) A first approximation of the relation between these sets has been established by applying a qualitative scale of relevancy numbers.

Yet to be established are the details, degree of utility, and the mechanics of application of this rationale.

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(2) "Goals and Objectives 1968-1987", "OSSA Prospectus 1967", Appendix A, National Aeronautics and Space Administration, Office of Space Science and Applications, September 1967.

(3) "NASA Program, Goals, Thrusts, and Broad Objectives", NASA Memorandum for the Planning Panel Chairman, January 8, 1969.

(4) "NASA OSSA Program Memorandua", August-September, 1968.

(5) "Objectives and Goals in Space Science and Applications - 1968", National Aeronautics and Space Administration, Office of Space Science and Applications, SP-162.

(6) "Space Science and Applications - Documents Prepared for the Defense Before the Congress of the Fiscal Year 1969 Budget", National Aeronautics and Space Administration, Office of Space Science Applications, Volumes 1 and 2.

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(10) "The Budget in Brief, FY 1969", U.S. Government Printing Office, Washington, D. C., 1968.

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CHAPTER III. SPACE PHYSICS

GOALS: To improve understanding of the nature of the space environment and the interactions and dynamic processes which control it

To explore new regions of space

To exploit space as a laboratory

RELATION OF SPACE PHYSICS TO NATIONAL GOALS:

PROGRAM OBJECTIVE AREAS	EDUCATION & KNOWLEDGE	SPACE	NATIONAL SECURITY	VETERANS	LABOR & MANPOWER	WELFARE	HEALTH	COMMERCE, TRANSPORTATION, & COMMUNICATIONS	GENERAL GOVERNMENT	AGRICULTURE	NATURAL RESOURCES & ENVIRONMENT	HOUSING & COMMUNITY DEVELOPMENT	INTERNATIONAL RELATIONS
NEAR-EARTH (TERRESTRIAL) SPACE	●	●	●								●		●
INTERPLANETARY AND GALACTIC SPACE	●	●	●								●		●
SPACE-AS-A LABORATORY	●	●	●								●		●

(Column group heading: NATIONAL (FUNCTIONAL) GOALS)

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CHAPTER III

SPACE PHYSICS

G. E. Wukelic

Introduction

Although the initiation of direct physical and geophysical measurements in the upper atmosphere began with rocket experiments in the mid-1940's, serious in situ sensing did not occur until the inauguration of the satellite era in 1957. The number and sophistication of both U.S. and U.S.S.R. artificial satellites and space probes, which soon followed, led to an accumulation of a wealth of new information about the normal and disturbed characteristics of the upper atmosphere and space environment. In addition to the discovery of new phenomena, fairly accurate definition and charting of the temporal and spatial variations of most of the previously known phenomena became possible for the first time. The principal utility of these space physics studies has been in making possible the assessment of the effects on and potential hazards to men and materials operating in this new environment, and in providing the foundation necessary for exploiting the application opportunities inherent in satellite technology.

Uncertainties, irregularities, controversies, and complexities inherent in much of the "space age" acquired data and knowledge, coupled with regions which as yet remain unexplored, combine to form the prime scientific requirement for continuing space physics studies in the future. The ultimate practical goal of acquiring sufficient understanding of the upper atmosphere and space environment to permit its accurate prediction and, in several cases, possibly its modification, provides the long-term incentive for this discipline. Also, because of the control that the Sun exercises over the Earth and space environment, future research efforts will emphasize solar-terrestrial relationships. This will necessitate observations over longer time intervals, preferably over several solar cycles.

Several government agencies, in addition to NASA, are involved in or support space physics research. These include, principally, the Department of Defense, the Atomic Energy Commission, the National Science Foundation, and the National Academy of Sciences. The functions of these agencies are strongly application or mission oriented and are not considered here, in detail. However, contributions of research to the objectives and missions of these agencies are included.

Space physics activities by NASA are currently an integral part of the OSSA Physics and Astronomy Programs Office. In this study, space physics is treated as a separate program area with its discipline components (i.e., particles and fields, ionospheric physics, etc.) being considered subprogram areas. For all practical purposes, space physics, as used in this analysis, includes geophysics and aeronomy.

In the discussions that follow an attempt has been made to identify the broad goals and objectives associated with this program area in general, and in several cases the more specific objectives of the subprogram areas. Also, the relation and relevancy of these objectives and/or activities to national goals are presented as is a summary of the flight program possibilities for the area. Because this study is primarily in support of space transportation system planning, space physics activities involving balloon, aircraft, and vertical rocket probes have been almost entirely excluded from consideration.

Goals and Objectives

Numerous available technical and planning documents identify goals and objectives in this area. The most definitive set of space physics goals for the immediate and near-future time periods is listed below. With minor exceptions, these goals correspond to those cited in the more current planning documents:[1-6*]

- To improve understanding of the nature of the space environment and the physical interactions and dynamic processes which control it
- To explore new regions of space
- To exploit space as a laboratory.

These goals are being realized through missions initiated under discipline-oriented subprogram objectives of the space physics program. In the discussion that follows, these subprogram objectives are defined, described, and assessed according to the following three functional space physics objective areas:

(1) Near-Earth (Terrestrial) Space

(2) Interplanetary and Galactic Space

(3) Space as a Laboratory.

These chosen functional objective areas parallel fairly closely the overall space physics goals designated previously and, at the same time, permit the discussion to be organized according to physically or geophysically related regions or activities.

The technical disciplines involved in each of the three functional subprogram space physics objective categories are noted below:

(1) Near-Earth (Terrestrial) Space Objectives

- Atmospheric structure and composition
- Ionospheric physics
- Particles and fields
- Solar physics (see "Space Astronomy" chapter)

(2) Interplanetary and Galactic Space Objectives

- Particles and fields
- Micrometeorites and interplanetary dust

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* Superscripts denote references cited at the end of this chapter.

(3) Space as a Laboratory Objectives

- Relativistic mechanics
- High-energy physics
- Controlled geophysical experiments
- Spacecraft-environment interactions
- In-space behavior of matter (solids, liquids, and gases)
- Plasma physics
- Manned experiments.

Terrestrial Space Objectives

Technological capabilities and scientific and military interests in both the U.S. and U.S.S.R. have been adequate to foster viable space programs which, up to now, have logically and successfully emphasized the exploration (automated and manned) of the near-Earth or terrestrial space environment. The definition of a meaningful boundary for the latter--that is, the magnetospheric boundary--was, in itself, one major result of this exploratory research. Both programs have made steady progress and are entering into an exploitation phase wherein scientific and technical knowledge acquired on terrestrial space is being utilized for the development of artificial Earth satellites having specialized military (e.g., reconnaissance), scientific (e.g., geodetic), and civilian (e.g., meteorological) applications. More recent plans for expanding satellite applications relate to the development of a global environmental monitoring and prediction system.[1,2,4,6,7]

One ultimate goal of both U.S. and U.S.S.R. space programs is the complete mastery of the terrestrial space environment. This goal includes the ability to understand, forecast, utilize, protect, and, in special cases, modify this environment. Such mastery over terrestrial space requires thorough understanding of its nature and variability. Its general features have been fairly well defined during the first decade of space research; adequate understanding of its variability (viz., spatial, temporal, and solar) and responsible processes constitutes the key target for near-Earth space research in the 1970's.[1,2,6-9]

In the discussion that follows, the scope and importance of activities and broad objectives associated with terrestrial, space physics research are considered for each of the following disciplines:

(1) Atmospheric structure and composition

(2) Ionospheric physics

(3) Particles and fields.

The closely related area of solar physics is treated in the "Space Astronomy" chapter.

Atmospheric Structure and Composition. This research activity has, as its major objective, the improvement in understanding the global nature of the chemical composition, temperature, pressure, density and dynamics of the upper atmosphere, and their variations with time, season, solar cycle, and geomagnetic activity. Results of such studies aboard rockets and satellites to date have been quite valuable in advancing scientific knowledge of the aeronomy of the upper atmosphere and in meeting the increasing space, civilian, and military needs for space environmental data. Recent examples of the latter include the application of atmospheric structural data or knowledge (temperature, pressure, and density) to ballistic missile and spacecraft design and operation (required for succesful launch, in-orbit maneuvers, station keeping, and re-entry operations), design of high-altitude high-speed aircraft, and for predicting and/or assessing the short- and long-term effects of environmental modification experiments such as Projects Firefly, Westford, Argus, and Starfish. Increased understanding of these basic atmospheric properties is also essential to the development of effective weather modification and control techniques.[1,2,4,5,7,8,10-12]

Ionospheric Physics. The program for this discipline consists primarily of two broad objectives: (1) to understand the origin, distribution, and temporal variations of ionized regions in the Earth's upper atmosphere, and (2) to obtain detailed knowledge of the interactions between the ionized regions and electromagnetic waves. The first objective emphasizes studies relating to understanding the photochemistry of ion production and loss mechanisms, dynamic processes controlling ion mobility and transport, and the global characteristics of the normal and disturbed ionosphere. The latter includes not only defining electron and ion distributions in the various (C, D, E, F_1, and F_2) regions, but also ascertaining the ionized conditions accompanying anomalies and irregularities such as sporadic E, spread F, Sudden Ionospheric Disturbances (SID's), Polar Cap Absorption (PCA), and Sudden Commencement Absorption (SCA). The second objective is self-explanatory since it concerns itself entirely with the practical aspects of determining the effect of various ionospheric conditions on the scattering, absorption, reflection, fading, and scintillation of radio waves.[1,3-6,12,13]

Although ground-based observations have historically provided most of the data on the nature and behavior of the ionosphere, the recent direct measurements by rockets and satellites have significantly contributed to knowledge of both the global description and the characteristics of the lowermost and uppermost regions of the ionosphere. The identification of specific space-age contributions to date, existing ionospheric problems, and recommended programs for future endeavors are contained in several recent reports. Many of these reports stress the need for better coordinated and simultaneous measurements in the future.[1,4,6,7,14-19]

Any progress in this discipline contributes directly to solving practical problems associated with understanding and forecasting ionospheric radio-wave propagation conditions and effects so important to communications, tracking, and detection functions. Techniques used to investigate the terrestrial ionosphere are also applicable in the exploration of planetary atmospheres, an area of research which is just beginning. Lastly, these studies provide important inputs to radio astronomical, auroral, and Very Low Frequency (VLF) observations as well as to plasma physics research in general.[1,2,7,12,17,19]

Particles and Fields. In all of space-science research, perhaps the most dramatic discoveries have occurred in the particles and fields area. The first major discovery of the space age, i.e., radiation belts, followed by the demonstration of man's ability to create such belts artificially, and more recently, by the discovery of a permanent natural boundary for the Earth's environment, termed the magnetosphere, are only major examples of satellite-inspired progress in this discipline to date. Although several aspects of these discoveries had been suspected, it remained for satellite measurements to confirm their existence and/or to identify their characteristics. However, after allowing for such noteworthy progress, the current level of knowledge of particles and fields is still frequently described as rudimentary. A wide variety of problems remain for future study.[2,7,15-17,20-22]

The broad objective in this discipline, insofar as terrestrial space is concerned, relates to improving the understanding of (1) the magnetic and electric fields of the Earth (including their temporal variations); (2) energetic particles (either individually or collectively); and (3) the interactions between particles and fields (including such related phenomena as aurora and VLF emissions). Specific objectives for this subprogram area have been publicized, but are too numerous to describe here.[2,3,5,12]

There is little doubt that studies in this area find maximum relevancy or utility for defining, assessing, and/or predicting the radiation hazard to men and material operating in space. Other essential applications of these studies include the ability to discern and predict the residual effects of artificial radiation induced by high-altitude nuclear explosions, assist in establishing the effect of energetic particles on radio communications, provide inputs to the design of spacecraft stabilization systems, and possess potential for supporting the development of new (plasma) power sources. Scientifically, these studies not only provide basic knowledge about the nature of the Earth's environment, but are important in that knowledge gained is directly applicable to other regions of the solar system and universe as well.[7,10,21,22]

Interplanetary and Galactic Space Objectives

Thorough understanding of the near-Earth space environment requires that all external forces influencing it be identified and researched. Accordingly, interplanetary and galactic space objectives (as well as some space astronomy objectives) are concerned with the solar wind (plasma), solar and interplanetary magnetic fields, solar and galactic cosmic radiation, and interplanetary dust. The objective of solar wind studies is to determine its origin, composition, variability, and relationship to solar conditions. Similarly, the nature and variability of the interplanetary magnetic field, which have been observed to originate at the surface of the Sun and to be carried by the solar wind to the Earth's vicinity, are of major concern to space physicists. Cosmic ray studies continue to seek improved understanding of the composition, flux-energy spectra, and temporal and spatial behavior of both solar and galactic radiation. Their origin, emission mechanism, and propagation characteristics are subjects of greatest current concern. Lastly, data on the nature and distribution of dust (micrometeorites) in cosmic and interplanetary space are high on the list of desired information. Existing uncertainties, controversies, and data voids require that additional measurements employing improved instrumentation schemes be made over different mass intervals and extended spatial regions. These studies as well as radiation studies noted previously have their maximum utility in the development of reliable methods for predicting interplanetary space radiation intensities and particulate populations that constitute the major hazards to man and equipment operating in the deep space environment. Results of such studies also provide clues to the nature, dynamics, and evolution of the galaxy which are of fundamental astrophysical and cosmological interest.[1-5,7,10]

Up to now, all direct measurements of the above spatial phenomena have been made at relatively short distances from the Earth and have been confined to the ecliptic plane. Appropriately, in the immediate to near future, plans for this area call for higher priority on programs aimed at extending this observational region by launching interplanetary probes out toward the orbit of Jupiter as well as out of the ecliptic plane.[1,2,7]

Space as a Laboratory Objectives

Perhaps the least emphasized space physics objective, to date, is that involving the proper utilization of the unique research laboratory environment which only space provides. Logical studies suggested and a brief description of their importance are given below.

Relativistic Mechanics. Delicate space experiments to test the general theory of relativity are under development. These include the comparison of the operation of ground and space-based nuclear clocks and observation of the precession of very accurate gyroscopic equipment. An initial experimentation in this direction was performed by the Soviets using a maser aboard Cosmos 97 in 1965. Results of such experiments could be of tremendous scientific value in that validation of the general relativity theory could improve understanding of the past, current, and future status of the universe, and could influence the development of better time standards and guidance equipment.[1,2,5,6,8,13,16,23-25]

High-Energy Physics. The major objective under consideration here involves the orbiting of a high-energy physics laboratory wherein the flux, energy spectrum, and charge spectrum of primary ultra high energy (10^2 to 10^4 Bev) cosmic rays could be assessed. Such studies are already in progress in the U.S.S.R. using the Proton satellite series. In addition to improving understanding of the nature of the universe, these studies could provide an insight into the basic structure of matter.[1,2,6,13,23-25]

Controlled Geophysical Experiments. To date, several experiments involving the controlled injection of chemicals and charged and uncharged particles into the upper atmosphere and near-Earth space environment (Projects Firefly, Argus, and Starfish) have been successfully performed. Numerous other environmental modification experiments have been proposed and are either undergoing evaluation or are being actively pursued. Examples of these last experiments include the orbiting of an accelerator or a large mirror and the releasing of a large quantity of barium into the tail of the magnetosphere. Most of the experiments performed or proposed have maximum utility for improving the understanding of the dynamics, structure, chemical processes, charged particle transport, and electric field conditions of the upper atmosphere as well as to aid basic cometary physics studies. These same experiments possess tremendous military potential since such important functions as the detection of missiles and nuclear explosions, communications, and battlefield illumination conditions can be influenced by such environmental modification practices. The potential and/or relevancy of such experiments is supported by the recent recommendation by the Space Science Board that increased support be given to controlled geophysical experiments during the 1968-1975 time period.[1,2,5-7,11,25]

Spacecraft-Environment Interactions. Included among the space physics objectives are plans to investigate more thoroughly the induced environment in the immediate vicinity of spacecraft. Studies relating to the mapping of the wake and dynamics of particulate debris (viz., luminescent particles) normally accompanying the flight of a spacecraft are contemplated. Experiments aimed at modifying this induced environment, such as by exciting the surrounding plasma with a radio transmitter, or by injecting substances such as water into it, are also among other possibilities that have been tried or suggested. These studies which lead to improved understanding of satellite-environment interactions could provide significant inputs to programs aimed at improving satellite measurement, tracking, and communication techniques.[1,2]

In-Space Behavior of Matter. NASA has an acknowledged interest in conducting physics experiments on either manned or automated spacecraft which will improve the understanding of surface forces, drop, bubble, and solid particle dynamics, and flame propagation in a gravity-free environment. Results of such experiments will have their maximum utility in improving man's ability to function safely and effectively in space.[1,2]

Plasma Physics. Space provides physicists with the opportunity to study plasmas over a range of parameters that are either too difficult or impossible to obtain in a laboratory. Since the plasma environments of Mars and Venus have been found to differ from those of the Earth, the continuation of studies aimed at comparing different plasma regimes, particularly from the standpoint of solar wind/atmosphere interactions in relation to atmospheric and magnetic field differences, is also considered as a near-term space physics objective. These studies not only shed light on plasma physics in general, but also on the nature and evolution of planetary environments.[1,2,7,25]

Manned Experiments. Objectives insofar as manned or man-assisted space physics investigations are concerned are indefinite. Although various physical and geophysical experiments and/or observations were successfully undertaken aboard both U.S. and U.S.S.R. manned spacecraft,[16,24,26] recent documents attesting to the need for manned space physics investigations in the future are rare. This is in contrast to the documents emphasizing man's future role in space astronomy[2,13,14,27-30] and, to a lesser extent, applications satellites[3,27]. Some planning documents refer briefly to the establishment of a manned-associated physics laboratory (with undisclosed experiments planned for the 1970's) or to the opportunities, in general, that may be available via piggyback arrangements with the Manned Orbital Laboratory (now cancelled), the Apollo Applications, and the Orbital Workshop programs.[1,2,5,6]

It is interesting to note that in the eight-volume assessment of the needs and requirements for a manned space station (prepared by the NASA Space Station Requirements Steering Committee in 1966), opportunities for manned, space-physics investigations are conspicuously absent. This is somewhat surprising since many of the missions noted above, could possibly be performed best by manned experimentation. Many of the suggested physical experiments are prerequisite to any serious attempt to utilize space for industrial purposes, such as materials and processing laboratories or unique manufacturing facilities.[5,6,30,32]

Relation to National Goals

The national importance of space physics research accomplishments and objectives can be assessed from two points of view. The first is the scientific significance of new discoveries and routine advances in understanding the dynamic processes shaping man's natural environment and the second is the practical relevancy (direct or implicit) of these accomplishments to man's everyday attempts to utilize, predict, and modify this environment. Both assessments show space physics objectives and activities to have their strongest impact on national goals concerned with national security, space, and education and knowledge. However, because of the global nature of space physics measurements, the world-wide interest in the results obtained and the number of countries participating in these endeavors, space physics has considerable effect on international relations. Since describing, understanding, and forecasting the atmospheric and space environment are major functions or responsibilities of the Environmental Science Services Administration (ESSA) of the Department of Commerce, space physics activities are directly related to the natural resources and environment functional field.

A subjective estimate of the relevancy of each category of space physics goals and objectives to these national goals is shown in Table III-1. A brief discussion summarizing the overall relationship of space physics objectives to each of these five basic national goals follows. Because of their remoteness, no attempt has been made to associate space physics objectives to the remaining eight functional national goals. Although several space physics developments, such as the micrometeoroid sensor and magnetometer have found application to nonspace related areas such as medicine and prospecting, technological spinoffs are difficult to forecast and accordingly are not explicitly considered in the following relevancy assessment.[10,33,34]

National Security

The military need for upper atmosphere and space environment data and knowledge was firmly established long before the space age began. However, the increasing sophistication of aerospace weapon systems and the expansion of military operations to global as well as spatial environs have enhanced the criticality of these needs. Granted that the basic responsibility for such R&D inputs rests with the Department of Defense, the space physics program has played, and is continuing to play, a key role in obtaining research results that have proven useful to various defense agencies.[8,11,12]

TABLE III-1. ESTIMATE OF THE RELEVANCY OF SPACE PHYSICS OBJECTIVES TO NATIONAL GOALS

Space Physics Program Objective Areas	Subprogram Topical Objective Areas	National (Functional) Goals: National Security	Education and Knowledge	Space	International Relations	Natural Resources and Environment
Near-Earth (Terrestrial) Space						
	Atmospheric Structure and Composition	4	4	4	3	3
	Ionospheric Physics	5	4	4	3	4
	Particles and Fields	5	4	5	3	4
	Solar Physics (see Space Astronomy Chapter)					
Interplanetary and Galactic Space						
	Particles and Fields	3	4	5	3	4
	Interplanetary Dust	1	3	4	1	1
Space as a Laboratory						
	Relativistic Mechanics	2	5	2	1	2
	High Energy Physics	3	5	3	1	0
	Controlled Geophysical Experiments	5	5	3	3	4
	Spacecraft-Environment Interactions	5	3	4	0	2
	In-Space Behavior of Matter	3	4	4	1	0
	Plasma Physics	2	4	3	1	3
	Manned Experiments	3	3	4	1	0

RELEVANCY RATING:

5 Critically Relevant
4 Fundamentally Relevant
3 Advantageously Relevant
2 Conveniently Relevant
1 Remotely Relevant
0 No Apparent Relevancy

Near-Earth Space Environment. As noted previously, a long-term goal of both U.S. and U.S.S.R. space programs is the ultimate mastery of terrestrial space, which inherently includes maximum exploitation for military purposes. Their space accomplishments during the first decade of space exploration is adequate testimony of the seriousness with which both countries researched and exploited this region.[6-8,17,24,35-37] Several specific examples demonstrating the applicability of space physics investigations of the near-Earth space environment to national defense have been cited previously. In retrospect, these applications related principally to the well-known relevancy of terrestrial space data and knowledge to the design and operation of high-flying aircraft, missiles, and satellites; to the execution of such important military functions as communications, missile and satellite detection, tracking, guidance and control; to the development of specialized satellites having surveillance, reconnaissance, and clandestine nuclear-testing detection missions; and, lastly, to the assessment and prediction of the initial and residual effects of man's attempts to modify and/or control this environment (i.e., ionospheric and magnetospheric modification experiments) which could be of major military significance.[1,2,7,10,11,38]

The impressive applications record cited above is the basis for the high relevancy rating assigned to the various terrestrial-space disciplines under the national defense category in Table III-1 since it must be assumed that evolutionary changes in military aerospace weapons and operations will require similar but improved terrestrial-space environment inputs in the future.

Interplanetary and Galactic Space. In comparison to terrestrial space, studies relating to defining the nature of interplanetary and galactic space must be viewed as being of considerably less significance to contemporary national defense needs. These studies do have some defense relevancy, however, in that they provide information on conditions existing in deep space that can be advantageously utilized in the development of reliable techniques for predicting conditions existing in the near-Earth space environment.[1,2,7]

Utilization of Space as a Laboratory. NASA programs aimed at conducting a variety of manned and automated physical experiments in space of the type which are not feasible on Earth are only in their preliminary stages. Several categories of gravity-free experimentation have received the highest relevancy ratings possible in Table III-1, based primarily on the high potential they possess for making significant inputs to national security situations in the future. Actually, the breakthrough potential inherent in several of these studies, could result in their being considered of higher priority than some of the similar but more routine terrestrial space investigations.

Education and Knowledge

Space physics contributions to the functional field, like the field itself, can best be described in terms of its two component parts: education and knowledge. The high relevancy rating ascribed to this goal on Table III-1 is due primarily to the fact that the chief product of all space physics investigations is the advancement of fundamental knowledge. Since the beginning of the space age, NASA has amassed a tremendous reservoir of pertinent knowledge pertaining to the nature of the near-Earth space environment and the processes that control it, has improved understanding of the nature of interplanetary space, and is currently on the threshold of exploiting space as a laboratory. Several experiments under consideration in the latter category possess high scientific breakthrough potential since the fundamental laws of the universe are under examination. In addition to advancing the frontiers of space physics, per se, space-age acquired knowledge has had a sizable impact on the character of other scientific disciplines such as geophysics, astrophysics, nuclear physics, and plasma physics. By far the strongest impact has been on the field of geophysics, which now encompasses many new and previously unsuspected areas for research.[1,2,6,7,12,25,39]

Although indirect, space science research, in general, and space physics endeavors, in particular, have been quite influential in the field of education. Commencing with improvements demanded in the structuring and quality of our entire educational system following Sputnik I, this influence has been manifest primarily through financial assistance to either educational institutions (via the creation of new facilities and/or research opportunities) or students (via scholarships and fellowships). Because many space physics endeavors involve the use of fairly simple rocket and satellite payloads, they have been the most effective in fostering the continued participation of the academic community. The importance of advanced education in space physics to the nation has been repeatedly stressed.[7,8,10,15,16,23,40-42]

By no means the least significant factor, the knowledge acquired and manpower educated under the auspices of the OSSA space physics program to date have played key roles in fulfilling another major NASA mission objective: to establish and maintain U.S. leadership in the overall space science area. However, the U.S.S.R. has evinced a national commitment and a level of competence in rocket and satellite research that represents a continuous challenge to U.S. space science leadership.[4,8,11,12,24,35-37,43]

Space

Historically, space physics has been the nucleus or foundation for the overall multidisciplinary field currently termed space science research. Accordingly NASA space physics objectives, activities, and accomplishments are fundamental to the establishment of NASA's space science image and to a lesser extent to that for the entire space program. In ascertaining the relevancy of each of the various space physics subprogram objectives to space, it has been necessary to evaluate them according to their significance to the following broad goals: (1) space science goals; (2) NASA space goals; and (3) functional field space goals. Although some duplication exists, for this report, these goals have been designated thus:

- Space Science Goals[1,2,4,6,12]

  (1) To master the near-Earth (terrestrial) space environment

  (2) To explore the solar system

  (3) To improve understanding of the universe.

- NASA Space-Act Goals[12]

  The objectives of space activities were set out in Section 102.(c) of the enabling legislation:

  (c) The aeronautical and space activities of the United States shall be conducted so as to contribute materially to one or more of the following objectives:

  (1) The expansion of human knowledge of phenomena in the atmosphere and space;

  (2) The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles;

  (3) The development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space;

(4) The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;

(5) The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;

(6) The making available to agencies directly concerned with national defense of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of information as to discoveries which have value or significance to that agency;

(7) Cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results thereof; and

(8) The most effective utilization of the scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment.

- The Bureau of the Budget Functional Field Space Goals[44]

  (1) To improve our ability to operate in the space environment

  (2) To advance man's knowledge of the universe

  (3) To use the experience gained for man's benefit.

The resulting relevancy ratings for the three designated space physics categories are uniformly high. This is expected, however, since each activity has been planned and/or funded to provide important and, in many cases unique, contributions to differing components of the overall space program. Many of these associations have been identified in the previous section and are not repeated here. However, it is readily apparent that the major benefits of these activities are associated with maintaining world leadership in understanding the space environment, assessing its effects on men and materials, and providing the scientific data base for continued exploitation of space for both civilian and military purposes.

International Relations

Space physics endeavors are associated with this functional field in several ways. One association is fairly indirect and relates to the enhancement of U.S. prestige throughout the world. Although not as pronounced as manned space spectaculars, advances and discoveries resulting from the NASA space physics programs have consistently underscored U.S. strength and leadership in the space science area. Similarly the dominating role maintained by the U.S. in the leadership, planning, and execution of international scientific activities concerned with space research, particularly those sanctioned by the International Council of Scientific Unions (ICSU), and the enthusiastic U.S. involvement in various space physics personnel and information exchange programs have been helpful in promoting a peaceful U.S. international space image.[4,8,11,12,14,35,40]

Another more direct association involves the establishment of cooperative space programs having formal commitments to both large and small foreign countries. NASA's international cooperative program, to date, has been largely space physics in nature and has involved the participation of over 80 countries. This program has included, for the most part, several joint satellite projects, individual experiments on NASA satellites, and extensive cooperative sounding rocket investigations all with non-Communist countries. Cooperative programs with Communist countries have been limited to bilateral agreements with the U.S.S.R.---providing selected data exchanges.[1,4,11,12,14,45,46]

The expertise derived from several areas of NASA space physics research is fundamentally relevant to assessing and predicting the global effects of selected environmental-geophysical modification experiments (e.g., Starfish, Westford, etc.), which understandably generate much international concern.[6,7]

The process of estimating the relevancy of the various space physics research categories to international relations or functions, as noted above, has been extremely difficult. The assigned ratings in Table III-1 are based on the fact that, although most associations have been via terrestrial space research, there exists a discernible trend to enlarge the scope of international efforts to include cooperative interplanetary missions (such as the planned U.S.-German solar probe) and possibly foreign experiments aboard manned flights.[1,2,4,7,8,12]

Natural Resources and Environment

In Reference 44, the Natural Resources and Environmental functional field was defined as including the nonmilitary space research performed by the Atomic Energy Commission (AEC) and the Environmental Science Services Administration (ESSA). Although there is some overlap with the AEC in terms of interest in background space radiation measurements, the major relevancy of NASA space physics objectives is to the latter. Actually, as can be seen in Table III-1, several NASA subprogram areas have been considered to vary from "advantageously to fundamentally relevant" to this functional field since ESSA maintains the nation's responsibility for describing, understanding, and predicting the state of the upper atmosphere and space environment; a responsibility being fulfilled through the Space Disturbance Laboratory. Actually this association could become even more relevant as the space physics needs associated with ESSA's future program thrust for developing a global environmental monitoring and prediction system come more sharply into focus.[6,11,44]

Future Flight Program[1,2,4-7,13,47,48]

Inherent in all NASA activities is the underlying requirement of effectively planning and developing both the necessary spacecraft and associated launch vehicles. The principal spacecraft for space physics investigations to date have been the multi-purpose Explorers, the Orbiting Geophysical Observatories, and the Pioneer space probe series. The space physics payloads that have been more recently noted as funded, planned, or proposed for each of the three subprogram objective areas along with the more pertinent associated launch features are shown in Table III-2. As is apparent from this table, there is a trend to develop smaller, less sophisticated spacecraft which will permit more frequent, better coordinated, and less expensive launches and which would require the minimum in the way of launch vehicle modifications in the intermediate to near-future time periods.

TABLE III-2. SPACE PHYSICS PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES(2)1,2,4-7,13,47-48

Spacecraft or Satellite Series	Prelaunch Designation	Projected Launch Date	Payload Size, inches and Weight, lb	Orbital Features	Launch Vehicle	Launch Site	Mission and Miscellaneous Remarks
			Near-Earth (Terrestrial) Space Flights				
Orbiting Geophysical Observatories (OGO)	OGO F (POGO)	1969	33x33x681 900	Low altitude polar orbit.	TAT-Agena	WTR	Last planned OGO launching. To conduct simultaneous measurement of particles and fields, atmospheric structural parameters, and ionospheric properties.
Delta Explorers							
(1) Interplanetary Monitoring Platform (IMP)	IMP G IMP H IMP I IMP J IMP K IMP L	1969 1971 1970 1972 1973-74 1974-76	52x38 400-500	High circular to highly eccentric polar and equatorial orbits	Delta (DSV-3E)	ETR/WTR " " " WTR	To undertake radiation studies throughout one solar cycle and to provide continuous radiation monitoring required for Apollo. Later versions to have on-board data processing capabilities.
	IMP M(Magnetotail Probe) IMP N IMP O(Magnetotail Probe) IMP P IMP Q	1974-76 1975-77 1976-77 1976-77 1977					
(2) International Satellite for Ionospheric Studies (ISIS)	ISIS A ISIS B ISIS C	1969 1970 1971	46x36 400-500		TAT/Delta/FW4	WTR " "	Spacecraft provided by Canada-launch vehicles by NASA. To make ionospheric measurements over one-half a solar cycle.
(3) Atmosphere Explorers (AE)	AE C AE D AE E AE F	1971-72 1972-73 1974-75 1976-77	300-400	Low perigee orbits.	TAT/Delta/FW4		Developed specifically to study atmospheric structural properties. To contain on-board propulsion capability for orbit adjustment.
(4) Cluster Satellites Series (CSS)	CSS A CSS B CSS C	1973-74 1975-76 1977-78			Delta		Single launch of several small satellites (2 to 4) in same Earth orbit within few km of one another. Primarily for particles and fields research.

(a) Includes all funded, planned, and proposed payloads except piggyback and cooperative opportunities.

TABLE III-2. SPACE PHYSICS PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES(a)1,2,4-7,13,47-48
(Continued)

Spacecraft or Satellite Series	Prelaunch Designation	Projected Launch Date	Payload Size, inches and Weight, lb	Orbital Features	Launch Vehicle	Launch Site	Mission and Miscellaneous Remarks
			Near-Earth (Terrestrial) Space Flights				
Scout Explorers							
(1) University Explorers	UE-A Owl UE-B Owl	1969 1969	20-330	Circular to highly eccentric orbits.	Scout Scout	WTR WTR	Small, university designed payloads for various Earth-orbit measurements.
	Injun						
(2) Small Scientific Satellite (SSS)	SSS A SSS B SSS C SSS D SSS E SSS F SSS G SSS H SSS I SSS J	1970 1971 1972 1973-74 1974-76 1974-77 1975-78 1976-79 1976-79 1977-80	20-330	Circular to highly eccentric orbits.	Scout	WI/WTR (Equatorial launch site under considera-tion)	Inexpensive payload capable of undertaking 4-6 experiments in earth orbit. Missions to include particles and fields, atmospheric structure and composition, and ionosphere investigations
(3) Cooperative Satellite German Research Satellites Italian Research Satellites	German A (Barium German B Release Probe) San Marco C	1969 1970 1970	20-330	Circular to highly eccentric orbits.	Scout	(Equatorial launch site under considera-tion)	Foreign countries provide payload, NASA supplies launch vehicle. To study atmospheric structure and ionospheric properties.
(4) Meteoroid Satellite	Meteoroid A Meteoroid B	1973-74 1975-76	20-330	Circular to highly eccentric orbits.	Scout		For specialized meteoroid studies.
Variable Orbit Scientific Satellites (VOSS)		?	1200	Low perigee polar & equatorial orbits.	Delta	ETR/WTR	Follow-on to Atmospheric Explorers with on-board orbital adjustment capability. Will measure atmospheric structure and composition, ionospheric properties, and particles and fields.
Geophysical Research Satellites (GRS)		Post 1971	120-150 (Instrumentation weight only)	Low altitude to highly eccentric.	Delta	ETR/WTR	Replacement of OGO with 12-15 experiment capacity. Will measure atmospheric structure and composition, ionospheric properties, and particles and fields within magnetosphere.
Space Geophysical Research Laboratory (SGRL)		1976	600	Low altitude to highly eccentric	Delta	ETR/WTR	Fairly complex spacecraft for continuous monitoring of all geophysical parameters.

TABLE III-2. SPACE PHYSICS PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES[(a)1,2,4-7,13,47-48] (Continued)

Spacecraft or Satellite Series	Prelaunch Designation	Projected Launch Date	Payload Size, inches and Weight, lb	Orbital Features	Launch Vehicle	Launch Site	Mission and Miscellaneous Remarks
			Interplanetary and Galactic Space Flights				
Pioneer							
	Pioneer E Pioneer H Pioneer I Pioneer J Pioneer K	1969 1974-75 1975-77 1976-? 1977-?	36x96 140-160	Heliocentric orbits (between 0.5-1.2 A.U.)	Delta (DSV-3L)	ETR	For synoptic interplanetary observations of particles and fields and interplanetary dust throughout solar cycle.
	Pioneer F Pioneer G	1972 1973		Planetary Cruise mode.			Actually under planetary exploration program, but will also undertake interplanetary studies out to several astronomical units from the Sun.
Scout Explorer Sunblazer	Sunblazer A Sunblazer B Sunblazer C Sunblazer D Sunblazer E	1970 1971 1971 1972 1972	20x24 15-60	Heliocentric orbits (perihelia between 0.4-1 A.U.)	5-stage Scout	WI	Small interplanetary probe for missions toward the Sun (primarily particles and fields). First flight of 5-stage Scout.
Solar Probe German Federal Republic	Solar Probe A Solar Probe B	1973 1974	48 to 120 250	Heliocentric orbits (perihelia between 0.1-0.3 A.U.)		ETR	Joint West Germany/NASA project for near-solar studies (primarily particles and fields).
Asteroid Probe	Asteroid Probe A Asteroid Probe B	1974 1976		To probe between the asteroidal belt and Jupiter (3-5 A.U.)		ETR	For interplanetary dust studies particularly in the asteroidal belt.
Galactic/Jupiter Probe			400-600 600-800	5 to 30 A.U. in the ecliptic. Also trajectories out of the ecliptic (using Jupiter swingby mode) are under consideration	$\leq$5 A.U. SLV-3X/ Centaur/ TE-364, $\leq$30 A.U. 260-SIVB/ Centaur/Kick	ETR	For interplanetary particles and fields measurements.

TABLE III-2. SPACE PHYSICS PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES(a)1,2,4-7,13,47-48
(Continued)

Spacecraft or Satellite Series	Prelaunch Designation	Projected Launch Date	Payload Size, inches and Weight, lb	Orbital Features	Launch Vehicle	Launch Site	Mission and Miscellaneous Remarks
			Space as a Laboratory Flights				
Relativity Satellites							
Hydrogen Maser		1973		Synchronous	Not determined	ETR	To test the general theory of relativity by measuring effects of gravity and motion on time.
Gyroscope		1975		Circular (300 nm)	TAT/Delta	ETR	To test the general theory of relativity by measuring the precession of an accurate gyroscope.
Physics Lab Satellites							
High Energy Lab		1974					Study program only.
High Energy Lab		1976					
Orbital Workshop							

For fulfilling near-Earth space objectives, NASA is placing heavy reliance on the Delta- and Scout-launched Explorers. Included in this category are the Interplanetary Monitoring Platforms (IMP)--which will incorporate on-board data processing computers--and the cooperative International Satellite for Ionospheric Studies (ISIS). Both of these are scheduled to begin in 1969. The maneuverable Atmospheric Explorers (AE), the Small Scientific Satellites (SSS) and the Cluster Satellite Series (CSS) are all scheduled to commence in the early 1970's.

NASA interplanetary and galactic space investigations in the near future are expected to continue to depend on the Pioneer series of spacecraft, which will incorporate various trajectory options. Additional flight support to this objective category will come with the introduction of the smaller, Scout-launched Sunblazer series in the early 1970's.

The major launch vehicle requirements associated with the space physics program area appear to phase in toward the second half of the 1970's. This corresponds to the time when larger payloads for the space as a laboratory objectives emerge and the trend in near-Earth and interplanetary investigations reverts back to the more complex payloads characteristic of the Geophysical Research Satellites (GRS), the Space-Geophysical Research Laboratory (SGRL), and the Asteroidal and Galactic probes currently envisioned for the late 1970's.

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CHAPTER IV. SPACE ASTRONOMY

GOAL: To undertake astronomical observations in space in support of ground based astronomical efforts to understand the origin, evolution, present structure, behavior, and ultimate destiny of the Sun, the solar system, and the universe

RELATION OF SPACE ASTRONOMY TO NATIONAL GOALS:

PROGRAM OBJECTIVE AREAS	NATIONAL (FUNCTIONAL) GOALS: EDUCATION & KNOWLEDGE	SPACE	NATIONAL SECURITY	VETERANS	LABOR & MANPOWER	WELFARE	HEALTH	COMMERCE, TRANSPORTATION, & COMMUNICATIONS	GENERAL GOVERNMENT	AGRICULTURE	NATURAL RESOURCES & ENVIRONMENT	HOUSING & COMMUNITY DEVELOPMENT	INTERNATIONAL RELATIONS
AUTOMATED ASTRONOMICAL OBSERVATIONS	●	●	●								●		●
MAN-ASSOCIATED ASTRONOMICAL OBSERVATIONS	●	●	●								●		●
GROUND-BASED ASTRONOMICAL OBSERVATIONS	NOT APPLICABLE - NO LAUNCH VEHICLE REQUIREMENTS												

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SPACE ASTRONOMY

G. E. Wukelic

Introduction

The term space astronomy (which combines one of the newest of research endeavors with one of the oldest) is used here to characterize activities concerned with undertaking astronomical observations* from above the Earth's atmosphere. It is not a new area of research, having evolved from balloon and rocket ultraviolet and X-ray studies of the Sun in the late 1940's and early 1950's.

From the very beginning, such astronomical observations were considered to have tremendous potential for making significant astronomical discoveries since they provided unique opportunities for astronomers to detect and analyze light from astronomical bodies in virgin regions of the electromagnetic spectrum. It has long been the dream of astronomers to overcome the control that the terrestrial atmosphere exerts over ground-based astronomical observations. The ozone in the atmosphere, for example, effectively absorbs all radiations with wavelengths shorter than 2,800 Å, and the same is accomplished by water vapor and carbon dioxide in the infrared region of the spectrum. There are currently two windows through which, from the surface of the Earth, astronomers can look into the cosmos beyond: the optical window from about 2,800 to 8,000 Å, and the radio window between 1 millimeter and 30 meters.

High-altitude balloons and, later, sounding rockets provided researchers and their first observational data on the nature of radiation in the ultraviolet, X-ray, and gamma-ray regions of the spectrum. It was, however, not until the space age that astronomers were able to make fairly routine, long-term satellite observations in these and other regions of the electromagnetic spectrum - principally those in the long-wave (radio astronomical) region.

When one considers the knowledge about the universe that has been accumulated by astronomers over the centuries via the narrow electromagnetic window, it is difficult to predict what advances and discoveries may be possible with the more direct contact with the universe that can be provided by rockets and satellites.

Although some advances have already been recorded, overall progress in this new research area has been slower than anticipated. Thus, the full impact of exploiting space technology for astronomical purposes remains in the future. For example, only a small number of high-altitude balloons and sounding rockets containing astronomical payloads are launched each year, and the use of astronomical observing equipment aboard high-flying aircraft (such as the X-15 and Convair 990) has been a fairly recent innovation. Astronomical sensing from satellites did not emerge until gamma rays were successfully recorded aboard Explorer satellites in the early 1960's, and it was not until 1965 that payload stabilization sufficient to permit the precise pointing at stars for stellar surveys was achieved. Similarly, the ability to develop and operate successfuly first-generation spacecraft designed especially for astronomical purposes, such as the Orbiting Solar Observatories (OSO) and Orbiting Astronomical Observatories (OAO), turned

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* At NASA OSSA this includes observations of the Sun, stars, galaxies, interstellar material and planets providing the observations are from near-Earth satellites. Observations of planets at close range are within the responsibility of the planetary programs office and are therefore treated in this report under the chapter on planetary exploration.

out to be much more complex than anticipated, and, accordingly, has only recently been demonstrated. Second-generation spacecraft, such as the Small Astronomy Explorer Series (SAS) (i.e., the Radio Astronomy Explorers, and Stellar X-Ray and Gamma-Ray Explorers) are currently emerging. The possibilities and options existing for future payloads of the large telescope and antenna array varieties, as well as complex orbiting observatories for manned astronomical observing and maintenance are receiving current planning emphasis. A planning void appears to exist, however, in evaluating the potential of lunar-based astronomical observatories.

In the management of the space-astronomy program, NASA has consistently recognized that space-astronomy efforts could not efficiently and effectively evolve without close cooperation and coordination with ground-based astronomical activities. Accordingly, NASA has tried to encourage both observational astronomers and astrophysicists to take an active role in the design, development, and utilization of space astronomical platforms and has supported ground-based astronomical activities considered important to the overall NASA mission.

Space astronomy activities at NASA are currently an integral part of the Physics and Astronomy Programs Office. However, as in the chapter on space physics, space astronomy is being treated here as a separate program area with its discipline components, viz., stellar astronomy, solar astronomy, X-ray and gamma-ray astronomy, radio astronomy, and infrared astronomy, being considered subprogram areas. In the discussions that follow an attempt has been made to identify the goals associated with this program area in general and, to the extent that information is available, the broad objectives of the subprogram areas. As in the other chapters, an estimate has been made of the relevancy of these activities to national goals. And lastly, a brief overview of the flight program possibilities for this area is provided.

The reader is cautioned that since this study is primarily intended to support space transportation system planning, activities involving balloon, sounding rockets, and aircraft platforms are, in general, excluded from consideration.

Goals and Objectives

Numerous recent NASA planning reports are available identifying goals and objectives in the space astronomy area.[1-12*] Several other published items of a more technical nature discuss current space astronomy objectives and activities in a more specific manner[13-18]. Also, numerous technical publications are available which contain generalized descriptions of recent spacecraft involved in space astronomy missions, specific observations undertaken, results obtained, and plans and/or recommendations for the future. Those of a more popular nature routinely being published include NASA presentations to Congress[19,20], NASA announcements of space flight research opportunities[21], and national reports to the Committee on Space Research (COSPAR)[22] and to Commission 44 (Astronomical Observations From Outside the Terrestrial Atmosphere) of the International Astronomical Union (IAU)[23]. Nonperiodic studies of special interest include those prepared by the Space Science Board[24-28] and the President's Science Advisory Committee (PSAC).[15] A chapter reviewing space astronomy activities in the U.S.S.R. to date is contained in the recently published Battelle Handbook of Soviet Space-Science Research.[29]

Of the numerous items available, few identify specific goals for the space astronomy program area. Older items mention only that the goal of the NASA space astronomy program is to undertake astronomical observations in space which cannot be obtained from the surface of the Earth. However, by combining portions of statements on space astronomy cited in three of the more recent NASA planning documents[1,2,4], and a

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* Superscripts denote references cited at the end of this chapter.

report of the President's Science Advisory Committee[15] the following broad goal can be derived: To undertake astronomical observations in space in support of ground-based efforts to understand the origin, evolution, present structure, behavior, and ultimate destiny of the Sun, the solar system, the stellar system, and the universe.

This goal is being realized through missions initiated under discipline-oriented subprogram objectives of the overall space astronomy program. In the discussion that follows, these subprogram objectives are defined, described, and assessed according to the following three functional categories of identified space astronomy interest:

(1) Automated astronomical observatories

(2) Man-associated astronomical observatories

(3) Ground-based astronomical activities (laboratory, theoretical, and observational).

These functional activities or interest categories have been chosen since they represent the type of activities in which NASA is or will be involved to fulfill the previously identified space astronomy goal. At the same time, such a categorization of NASA activities permits the discussion of the respective scientific objectives to be oriented toward the associated types of space transportation systems required. Accordingly, the technical disciplines involved in each of the three functional subprogram activity areas noted above are as follows:

(1) Automated astronomical observatories

- (a) Solar astronomy
- (b) Stellar (optical) astronomy
- (c) High-energy (X-ray and gamma ray) astronomy
- (d) Radio astronomy
- (e) Infrared astronomy
- (f) Planetary astronomy/planetology (see chapter on planetary exploration)

(2) Man-associated astronomical observatories

- (a) Solar astronomy
- (b) Stellar astronomy
- (c) High-Energy astronomy
- (d) Others

(3) Ground-based astronomical activities.

Automated Astronomical Observatories

The broad objective here is to develop and utilize specially instrumented satellites in automated modes for the purpose of conducting astronomical investigations in all regions of the electromagnetic spectrum. Specifically this includes the study of all radiations (gamma rays, X-rays, ultraviolet, visible, infrared, and radio frequencies) being emitted from extraterrestrial bodies and from remote regions of space. The current space-astronomy program is heavily dependent on such automated observatories since they provide an effective and fairly economical means of acquiring a wide range of observational data over long time intervals. Data rates are adequate for all types of experimental data except for the transmission of high-resolution images. Also, pointing and stabilization capabilities so important for space astronomical observing have undergone major improvements and are currently adequate to support all but the most sophisticated astronomical positional observations. Also, although manned astronomical missions are receiving increasing attention, *in situ* space measurements conducted with automated spacecraft are expected to continue to play the major role in space astronomy. This is because of the economy factor and because space astronomy requires a variety of orbits and trajectories which are not readily adaptable to manned missions.[6,8,16]

<u>Solar Astronomy</u>. Solar astronomy is concerned with the study of the evolution, structure, and behavior of the Sun. The broad NASA objective here, however, is to conduct solar experiments and observations above the Earth's atmosphere to improve observational techniques and understanding of solar phenomena, especially those influencing the Earth, planets, and interplanetary space. Such observations, which are independent of meteorological conditions provide the first opportunity to observe the Sun over long periods of time in all regions of the spectrum, as well as to obtain photographic and spectrographic records of small solar features. These observations are important for determining time-dependent solar activity variations of the type required for improving understanding of the complex solar-terrestrial interrelationship[9,26].

Because of the intensity of solar radiation and the control it exerts over terrestrial, planetary, and interplanetary environments, it is logical that space-based studies of the Sun have led all other areas of space astronomy endeavors. The extent of this research activity in terms of observations undertaken, results obtained, and research activities planned are adequately described and summarized in numerous NASA publications[1-10], in U.S. national reports to the Committee on Space Research (COSPAR)[22], and to Commission 44 (International Astronomical Union)[23], as well as in numerous other specialized reports and monographs on the subject.[12-21,24-27,29] The purpose of this section is not to review this tremendous volume of readily available information, but rather to present briefly the major findings and objectives in this area as well as some indication of the significance or value of accomplished and planned activities.

There have been ground-based observations of the Sun since the time of Galileo i.e., since the discovery of sunspots. The sunspot cycle is obviously the most striking manifestation of variable solar activity but it undoubtedly depends on a more fundamental cycle in the interior of the Sun and was expected to show better in the ultraviolet region of the spectrum. Even the first attempts to obtain the ultraviolet spectrum of the Sun by means of rockets were successful, and gradually the solar spectrum down to one Å became well known. It even became possible to use high-altitude aircraft to check on Earth-based determinations of the solar constant, which are necessarily uncertain as they require an extrapolation outside the terrestrial atmosphere. For example, recent aircraft measurements at 83 kilometers showed the value of the solar constant to be 2.5% less than that determined from ground-based measurements[30]. This is a significant result which serves well to demonstrate the need for space-based astronomical observations, since the variation of the solar constant is now considered to be the chief factor in the secular variation of terrestrial climate. The importance of such solar observations has long been realized by NASA, and accordingly four stabilized Orbiting Solar Observatories (OSO) have been developed and launched since 1962.

These satellites and similar studies aboard rockets have shown that the solar atmosphere is smaller than previously maintained during active periods; that the X-ray emissions are characterized by variability; that the definition of an optical solar flare is inadequate; and that correlations among optical, radio, and X-ray events are only partial. In spite of significant findings such studies fall short of the ideal requirement, one of fundamental importance in the problem of solar terrestrial relationships, which is the continuity of observation over at least one solar cycle (11 years), and preferably over several cycles. Only then can significant correlations between solar activity and its terrestrial manifestations be reliably established and more meaningful indices than sunspots recognized to give a better correlation with geophysical processes.[11,31]

Although it is difficult to determine where observing for scientific or exploratory purposes ends and routine monitoring for forecasting purposes begins*, it is certain that NASA should maintain some responsibility for providing solar observing continuity. It is therefore necessary to consider some sort of permanent OSO equipped for the purpose of making continuous observations of the Sun. At the present time it seems that the useful life of an OSO is of the order of 1 year with the possibility of extending this limit in the future. There should then be a series of OSO every year (starting now), with identical equipment to ensure the uniformity of record during the 11-year solar cycle. Such a program could make an extremely useful contribution to the understanding of both solar physics and geophysical responses to solar activity. It is these types of data or records which constitute the backbone of astronomy[31].

Specific solar astronomy problem areas which have been identified as requiring emphasis in the future are as follows:[5,6,25-27]

- Solar constant Does it really vary with the cycle? Variation as great as 2% had been reported from the study of the reflected light of the planets during the last cycle. Is there any indication of a long-period trend, such as an 80-year period which shows itself in spot numbers and areas covered by them?

- Ultraviolet and X-ray region Emphasis should be placed on this area in an effort to answer the problems of solar activity resulting in sunspots, flares, prominences, etc. In the recent experiments with OSO 4 excellent photographs of the Sun at λ 1032 Å and λ 625 Å were obtained so that a survey of the Sun in the ultraviolet region has been proved feasible. The solar photographs are still of rather poor quality but the techniques for such studies in both the U.S. and U.S.S.R. are rapidly improving.

- Solar wind Of interest are, particles escaping from the Sun and affecting the atmosphere of the Earth. Of special importance here are cosmic rays generated presumably by solar flares. Techniques already exist for study of cosmic rays both from the Sun and from outer space.

- Other details of the solar surface Solar features such as prominences, spicules, plages, flares, etc., follow the sunspot cycle. In fact, the Sun should be under constant observation from space. This would require a vehicle with a polar, or, at any rate, highly inclined orbit. Such as continuous program would be a very important supplement to analogous observations carried out at some 20 astrophysical observatories on the surface of the Earth.

- Solar magnetic fields They appear to be closely linked to solar activity, but the relationship is poorly understood. The relationship of solar magnetism to plasma velocity distributions and thermal structures remains one of the most pressing tasks of solar astronomy. Recent efforts, particularly in the U.S.S.R., have been expended on utilizing magnetic field gradients for forecasting solar flares. The resolution of ground-based observations remains inadequate to resolve important but small magnetic features. Therefore space-based observations have the potential to improve understanding of the origin and behavior of the Sun's magnetic field, which is so important in establishing better solar forecasting techniques.

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* A responsibility assigned to the Environmental Science Services Administration (ESSA). This routine ESSA activity also contributes to determining future space transportation system needs.

It is appropriate here to note briefly the primary value of such solar astronomical studies. The Sun, being such a nearby star, serves as both a theoretical model and photometric and spectroscopic standard for all stellar research. The understanding and forecasting of solar activity and its effects on planetary and terrestrial environments such as on ionospheric and aurora phenomena, the maintenance of heat budgets, meteorological and cosmic radiation conditions, as well as its effects on life that exists on planets (including the Earth) are directly dependent upon such studies. The Sun, which exhibits unique combinations of temperature, density, and other physical properties quite beyond terrestrial simulation, serves as a valuable, large-scale laboratory for astrophysics, aerodynamics, nuclear physics, spectroscopy, plasma physics, and magnetohydrodynamics.[3,5-9,27]

Stellar (Optical) Astronomy. It has long been known in principle that the ability to make observations from above the atmosphere would greatly increase the effectiveness of optical telescopes. Not only does this permit the extension of the observational range to the ultraviolet and infrared regions of the spectrum but it also provides a better operating environment. This environment is essentially free of stress due to gravity as well as free of atmospheric scintillation and image motion so detrimental to ground-based astronomical observing. Accordingly, employment of large optical telescopes in space, designed to detect and analyze extremely faint light sources originating from remote stars, nebulae, and galaxies, has been viewed as offering great promise since it contains high "breakthrough" potential of the type that could revolutionize astronomical science. However, because of the size and complexity of the equipment involved, this field has developed very slowly. Even with small telescopes on sounding rockets, precise pointing towards astronomical bodies other than the Sun is technically difficult, and not until 1965 was stabilization sufficiently precise to obtain ultraviolet stellar spectra with enough resolution to show the strong absorption lines. Similarly the development of the highly-stabilized Orbiting Astronomical Observatory (OAO) was much more difficult than anticipated and only after several years of additional redesign, development, and testing did it become possible to launch the first successful OAO on December 7, 1968.[11,32,33]

The Orbiting Astronomical Observatory (OAO 2) is the largest, heaviest, and most complex automated astronomical satellite launched to date and, although experiencing some stabilization difficulties, has successfully begun to map the sky in the ultraviolet region of the spectrum. The next OAO is to contain a large instrument for moderate dispersion ultraviolet spectrophotometry. This instrument will measure the ultraviolet energy output of most major classes of stars and provide information on stellar chromospheres. The subsequent OAO (OAO C) is designed to provide high-resolution ultraviolet spectrometry. Its function will be to provide long-term spectroscopic observations and provide for detailed study of selected astronomical objects with a pointing accuracy of 0.1 seconds of arc. This spacecraft will also provide substantial data on interstellar gases and interstellar dust.[2]

Stellar or optical astronomy in space is generally considered to include all astronomical research carried out in space at wavelengths from 800 Å to 1 millimeter, excluding solar studies. However, in this analysis observations between 1 micron and 1 millimeter are considered separately under the category of infrared astronomy. Few specific objectives for this area have been publicized but the broad objective appears to be one of designing, developing, and utilizing highly-stabilized automated space observatories for telescopic observations of celestial objects in the ultraviolet to visible regions of the electromagnetic spectrum. Specific questions frequently associated with current space optical astronomy efforts include the following:[9,11,26]

- What is the total radiation emitted by stars of each spectral type and how is this radiation distributed?

- Why do apparently similar stars differ so much in their ultraviolet signatures?

- What is the composition, density, and structure of the interstellar dust and gas?

- What are the major molecular constituents in interstellar gas?

- What is the spectral distribution of the energy emitted by emission nebulae and what are the details of the energy balance problem for these objects?

An overview of the generalized needs in this area is contained in the latest NASA OSSA Prospectus.[5]

As noted previously, stellar and galactic observations prior to OAO 2 were limited by the absence of spacecraft capable of making long-term observations. However, balloons and sounding rockets demonstrated the feasibility of such observations and have performed the first preliminary survey in the ultraviolet region. Major conclusions based on these observations are listed below:[6]

- Observations of stars in the ultraviolet region indicate a difference of observed light intensities in these wavelengths from what had been anticipated based upon extrapolation of visual wavelengths

- Temperatures of hot stars have been revised downward as a result of these ultraviolet observations

- Indications of mass loss from the largest, hottest stars have resulted in decreasing the estimate of time spent by these stars in their early stage of evolution

- A spectrum of a very hot, massive star revealed a number of new, unidentified, strong absorption lines not previously observed.

Other categories which are likely to benefit from space optical astronomy endeavors include[15,26]

- <u>Cosmic distance scale</u> Apparently large diffraction-limited telescopes in space are capable of producing sharper stellar images which could extend the current observational range to much more distant galaxies.

- <u>Structure of nuclei of galaxies</u> Nuclei of galaxies are too small to be resolved with existing telescopes. However, apparently a diffraction-limited 120-inch telescope in space could reportedly resolve sufficiently to permit completely decisive interpretations of the nuclei of galaxies.

- <u>Molecular hydrogen</u> There is apparently no way of detecting interstellar hydrogen directly from the ground. Observations with a space telescope in the ultraviolet (and infrared) range could perhaps determine with precision the spatial distribution and the temperature of hydrogen.

- <u>Stellar evolution and origin of the universe</u> By extending the range of accessible wavelengths and the levels of faintness, better estimates of stellar evolution and the origin of the universe may be obtained.

- <u>Detection of remote planetary systems and possibly extraterrestrial life</u> By permitting an increase in the sharpness of images attained, such observations will permit an attack on the existence of remote planetary systems, some of which may harbor life.

High-Energy (X-Ray and Gamma-Ray) Astronomy. This new area of astronomical endeavor began initially with rocket and balloon observations. The first satellite measurements were performed by Explorer XI with follow-on studies being subsequently undertaken on the Orbital Solar Observatories. Although the broad objective here is one of improving X-ray and gamma-ray observing techniques and understanding of the nature of the emitting sources, specific objectives for X-ray and gamma-ray astronomy have been delineated in the Woods Hole study[26] and in several NASA planning documents.[5-7,9]

To date, the brighter sources have been identified and gross features of their spectra recorded. Perhaps the most outstanding discovery has been the strong X-ray emissions observed from various small regions of the sky, such as in the Crab nebulae. A large number of X-ray sources have subsequently been found, often in galaxies. Their discovery is likely to have great impact on the formulation of concepts relating to the character of the galaxy. These observations will be continued employing improved sensor sensitivity during the Astronomy/Explorer (Small Astronomy Satellites, A and B) series, which will also permit studies of the variations in source intensities. Later, larger more complex instruments are planned which will extend these surveys to fainter magnitudes and to higher resolutions. Ultimately, instruments sophisticated enough to survey individual X- and gamma-ray sources are envisioned.[2,6,15]

It is hoped that this new field will help solve many fundamental astronomical problems. For instance, information should be forthcoming which will shed light on the mystery of pulsars, the origin and distribution of cosmic rays, the strength of galactic and intergalactic fields, and the nature (temperature, density, and composition) of galactic and intergalactic material.[5,26]

Radio Astronomy. Radio astronomy, another fairly recent branch of astronomy, has also been extended to above-the-atmosphere observing. Initial endeavors have shown that long-wave radio astronomical measurements above the F_2 region of the ionosphere are quite practical. Actually, orbiting radio telescopes are not only capable of receiving all signals originating in space but, because of the shielding provided by the ionosphere below, are also freed from interference from man-made signals generated on the ground. Although tremendous opportunities exist here for making significant research advances, the capability of utilizing orbiting radio astronomical equipment is only in its infancy. To date, rocket observations have mapped portions of the low-frequency radio spectrum and several successful radio astronomical experiments have been undertaken aboard the Orbiting Geophysical Observatories (OGO), the Applications Technology Satellite (ATS), and the Interplanetary Monitoring Platform (IMP). However, extensive radio surveys of the galaxy are only now being considered a possibility with the emergence of the Radio Astronomy Explorer (RAE) satellites, which are instrumented for recording radio emission between 0.5 MHz and 10 MHz. To achieve sufficient angular resolution to study individual radio sources, however, very large radio astronomical telescope apertures (up to 10 kilometers) are required. Because of the cost involved in launching such complex radio telescopes, this objective may have to be postponed until the development of the National Astronomical Space Observatory (NASO). Other specific objectives for solar, planetary, and galactic and extragalactic radio astronomical observing have likewise been delineated in the Space Science Board Woods Hole study.[2,5,26]

Radio astronomical observations from space platforms may be especially valuable in the solution of a great variety of galactic problems. For instance, they may reveal whether cosmic ray formations are a primary or secondary process. Interstellar grains may be studied in the radio region to determine the nature of the charge buildup on them. Radio astronomical celestial surveys could also help resolve existing controversies among various cosmological theories by way of providing additional information on the nature and variability of pulsar and quasar emissions.[2,5]

Infrared Astronomy. The terrestrial atmosphere has seriously limited the ability of astronomers to make observations of celestial bodies in the infrared region of the spectrum. Although there exist narrow regions (or windows) of the spectrum where atmospheric absorption is low enough to permit observations from selected observing sites on the ground, there has been a certain amount of growing enthusiasm the last 10 years or so for undertaking such observations in the 1 μ to 1 millimeter range, from high-altitude platforms. However, efforts to exploit infrared astronomy from space-based platforms have been severely handicapped because of the lack of suitable detectors (since liquid helium temperatures are required in these types of measurements), particularly for long-term satellite use. Therefore, activities to date have been limited to a few balloon, aircraft, and rocket measurements, which have provided coarse photometric and spectroscopic records of the infrared emission of the brighter planets and a few cool stars. As currently envisioned satellite infrared observations will not be possible until perhaps the sophisticated National Astronomical Space Observatory (NASO) is developed.[2,15,26]

In addition to ultimately providing a map of the celestial sphere in the infrared region of the spectrum, which would not only indicate the position of various infrared sources but their approximate brightness as well, these studies should lead to an improvement in the estimate of the total interstellar absorption. Also, by providing observational data of the infrared emission of low-temperature astronomical objects, such as dark interstellar clouds, globules, protoclusters, and protostars, a better understanding of the nature of these objects and of their role in the evolution of stars and galaxies would evolve.[2,9,26]

Man-Associated Astronomical Observatories

Based on past developments and current programs in planning, man's role in a space research capacity will most likely be realized initially in some space astronomy function. If things go as planned, between the automated observatories currently in use and the supersophisticated observatories of the future, man will be phased into the space astronomy program to an increasing degree. The proven ability of man to make selected astronomical observations aboard the Mercury, Gemini, and Apollo spacecraft combined with the upgraded payload capacity available via Saturn have resulted in serious planning considerations being given to utilizing man in a space astronomy role. It appears quite clear that, at least initially, this role will be more of a technical nature, i.e., one involving the installation, maintenance, repair, and replacement of equipment as opposed to a scientific observing function. It has been postulated that the incorporation of man in space astronomy missions could provide for enhanced reliability, improved pointing or stabilization capabilities, longer lifetime, as well as the ability to incorporate improved astronomical equipment into previously established observatories.[2,5,6,8]

Although it is difficult to determine the boundaries of interests or responsibilities between the manned and automated NASA programs, it is clear from published planning, progress, budget, and contractor reports that both have a very strong interest in manned space astronomy programs.[1-11,34-37] In addition, advisory groups such as the Space Science Board, the President's Science Advisory Committee, and the astronomical community in general appear to favor the incorporation of man into the space astronomy program.[2,10,15,32-37]

Mission categories under consideration for manned, space astronomy activities parallel fairly closely those associated with the automated astronomical observatories discussed previously. Initial payloads under development involve solar astronomical objectives whereas subsequent payloads include optical astronomy, and to a lesser extent, high-energy and radio astronomical objectives. Ultimately integrated functions required for all phases of astronomical observing are planned for the National Astronomical Space Observatory (NASO) currently visualized for the middle to late 1980's. In the sections below a very brief overview is presented of the programmed and/or planned activity associated with man's role in each of the major astronomical subdisciplines. Once again, little information was noted concerning a possible astronomical role for man on the moon (other than for lunar studies per se).

Solar Astronomy. In combination with and as a follow-on to the orbiting solar observatory activity, the Office of Manned Space Flight is developing the Apollo Telescope Mount (ATM) payload, scheduled for launch in late 1971 or 1972. If accomplished, this mission will represent the first major utilization of manned flight capabilities for astronomy. The objective here is to examine the problems and develop the techniques for supporting manned astronomical observing in space. Initial flights are to concentrate on observations related to the structure and dynamics of the solar corona, chromosphere, and photosphere. Later flights will perform spatial and low-spectrum resolution surveys of the celestial sphere in the ultraviolet, X-ray, and gamma-ray portions of the spectrum. Knowledge and experience gained from the ATM program should explicitly contribute to a better understanding of the Sun as well as determine man's ability to perform astronomical observations in the space environment.[2,6,8]

Stellar (Optical) Astronomy. As an intermediate step between the automated Orbiting Astronomical Observatories (OAO), the first results of which are only currently being realized through OAO 2, and the projected super-sophisticated manned National Astronomical Space Observatory (NASO), a program is underway to develop a man-associated Astronomical Space Telescope Research Assembly (ASTRA) capable of performing high-resolution observations of the planets, stars, and galaxies. Although the details of the system are still undefined, initial plans call for its launching sometime in the mid-1970's.[1-6,8]

High-Energy (X-Ray and Gamma-Ray) Astronomy. Studies of solar X-ray emission are a part of the ATM mission. However, larger and more complex instruments are believed necessary to study variations occurring over the entire celestial sphere in X-ray and gamma-ray radiation as well as for the study of individual X-ray and gamma-ray sources. It is possible that these objectives can be satisfied by automated spacecraft, although current considerations are being given to incorporating such experiments on man-maintainable space platforms, such as in the Orbital Workshop Experiments (OWSE) program.[2,4]

Others. The most ambitious long-range payload for the space astronomy program area appears to be the establishment of a National Astronomical Space Observatory (NASO). Although still in its early planning stages, this national facility scheduled for launching in the early 1980's is to combine the optimal sets of equipment for sensing in all wavelengths with man's ability to support sophisticated long-term observations. As envisioned, observations would be made of the Sun, planets, stars, interstellar gas and dust as well as specialized studies of unusual objects such as X-ray and radio stars, quasars, and pulsars. It is hoped that the NASO may answer such fundamental questions as: How curved is space? Is the edge of the universe observable? Does the universe age as a whole? What is a quasar? What other kinds of unknown astronomical objects exist? Overall NASO observations could be of vital importance to increasing understanding of the evolution, present conditions, and likely future of the solar system and the universe. In addition, the use of man in the adjustment, maintenance, and modification of the instrumentation package should permit this type of facility to be used for several decades on a wide variety of problems by many astronomers both in this country and abroad.[2,3,6,8]

Ground-Based Astronomical Activities

The necessity of having a strong, ground-based astronomical program to complement OSSA space astronomy activities has been consistently voiced by NASA[6,9,17], the Space Science Board[25-26,28], as well as by the President's Science Advisory Committee.[15] Although NASA has been awarding contracts to numerous scientific institutions, primarily to astronomical observatories, to carry out certain fundamental studies in addition to those directly supporting space flight investigations, very little has been published noting specific objectives of this activity. With the exception of the August, 1968, report on the NASA Space Science and Applications Program[9], few items are available which identify the scope and funding of NASA grants and contracts in this area. In the absence of a clear definition of NASA's objectives in this supporting research area and because of the effect such commitments could eventually have on NASA space-based missions, a brief examination was made of such activities.

It has been estimated that over 80% of the federal support to astronomy comes via NASA grants and contracts. Some 346 grants and contracts have definitely been identified that refer to the general area of astronomy, which includes, in this particular instance, activities associated with lunar and planetary astronomy as well. During the period under examination, almost exclusively 1964-1968 (i.e., in 4 years), NASA's expenditures in this support area approached $80 million. A breakdown of the entries according to astronomical disciplines involved is contained in Table IV-1.

TABLE IV-1. ESTIMATE OF NASA SUPPORT TO GROUND-BASED ASTRONOMICAL RESEARCH (1964-1968)[9]

Subject	Amount $, Millions	Percent
Solar Astronomy	6.9	8.7
Stellar Astronomy	4.3	5.4
Moon	11.3	14.3
Planets	15.2	19.2
Meteors & Plasma	13.6	17.2
Instrumentation	17.8	22.4
Celestial Mechanics	1.4	1.8
Miscellaneous	8.7	11.0
TOTAL	79.2	100.0

The expenditures noted in Table IV-1 do not represent NASA's total ground-based astronomical commitment. Considerable research done at NASA Centers is not included in these figures, nor are the investigations in geophysics, biology, chemistry, etc., which often have a close relationship to astronomical research.

These figures indicate that NASA has been providing support to American astronomy for the last 4 years at a rate of about $20 million per year. In terms of NASA's total annual budget, this expenditure is less than 1%. However, it may exceed the combined annual budget of all astronomical observatories and institutes in the U.S. provided by their parent institutions. The annual budgets of very few astronomical establishments in this country exceed $200,000 or $300,000.[31] It has been suggested that NASA expenditures at such institutions as the Massachusetts Institute of Technology or Harvard University, each receiving over $5 million during the period under consideration, may have created a serious imbalance in academic activity.[9] A fantastic growth in undergraduate and graduate school enrollment and instruction in astronomy and astrophysics has been the principal result of this activity. This growth has occurred not only at institutions involved with NASA contracts but by reflex action, at institutions having no direct dealings with NASA. The tremendous impact that NASA has had on graduate school enrollment and PhD production in astronomy and astrophysics is summarized in a recent report on NASA university programs.[38]

NASA has thus developed a large group of highly trained personnel which constitute a valuable national asset and which depend almost entirely on NASA's further undiminished support in this area. However, it now appears that one of the most serious cuts in the NASA budget occurred in this area. From a high of $46 million for "sustaining university programs" in 1966, the appropriation for the same purpose in 1968 was only $10 million. The seriousness of this situation has been noted by the Space Science Board.[26] Concern has also been expressed over NASA investments in improving old and establishing new astronomical facilities without an apparent clear definition of coordinated goals and objectives.[31]

Relation to National Goals

Characteristic of all purely fundamental research endeavors, accurate assessment of the national importance or significance of space astronomy objectives and/or activities is extremely difficult. However, recognizing this difficulty, an attempt has been made first, to associate space astronomy endeavors with some 13 national functional goals (previously identified)[41], and second, to estimate the potential relevancy of such endeavors. For example, it is apparent that space astronomy objectives and activities are closely associated with national education and knowledge interests and accordingly make their strongest impact on this national goal. Likewise there is little doubt that, if man's ultimate space goals are to be achieved, space astronomy endeavors will play a key role. To a lesser degree it has been found possible to associate space astronomy objectives with specific national security needs and functions, natural resources and environmental activities, as well as to international relations. The association and relevancy of space astronomy activities to the remaining eight national goals are considered too nominal to merit discussion.

A quantitative estimate of the relevancy of space astronomy activities to these five national functional goals is shown in Table IV-2. A brief discussion summarizing the overall relationship of space astronomy activities and objectives to each of the five national goals identified above follows.

National Security[16,39]

Space astronomy applications to national-defense activities are relatively well known. Thus, the high relevancy ratings assigned to several of the subprogram areas in Table IV-2. The nature of these applications fall into two distinct categories - scientific and technological. Scientifically, space-solar astronomy activities are of direct military significance in that they include efforts to improve understanding of the nature and behavior of the Sun so that more accurate forecasting of ionospheric disturbances, such as those which disrupt intercontinental communications and missile detection systems, can be accomplished. Improvements in understanding the solar-terrestrial relationship, controlling as it does near-Earth radiation environment, are important to successful employment of DOD nuclear-detection satellites and for safe utilization of manned-military space systems such as the Manned Orbiting Laboratory (MOL).* Results of ultraviolet and infrared surveys of astronomical bodies from space and the subsequent preparation of celestial maps have valuable application to such militarily significant functions as navigation, guidance, and ICBM and/or spacecraft detection.

Spectroscopic data being accumulated on stellar atmospheres will aid in the study of plasma, which in turn should help in the design of advanced nuclear power systems. Studies of physical and chemical processes occurring on the Sun and stars, processes which

* Which was canceled in June, 1969.

TABLE IV-2. ESTIMATE OF THE RELEVANCY OF SPACE ASTRONOMY OBJECTIVES TO NATIONAL GOALS

Program Objective Areas	Subprogram and Topical Objective Areas	National (Functional) Goals: National Security	Education and Knowledge	Space	International Relations	Natural Resources and Environment
Automated Astronomical Observations	Solar Astronomy	5	4	5	4	4
	Stellar Astronomy	3	5	4	3	0
	Planetary Astronomy[(a)]					
	High-Energy Astronomy	3	5	4	3	3
	Radio Astronomy	3	5	4	3	2
	Infrared Astronomy	5	5	4	3	1
Man-Associated Astronomical Observations	Solar Astronomy	2	2	2	3	2
	Stellar Astronomy	2	2	2	3	0
	High-Energy Astronomy	2	2	2	3	1
	Other (Radio, Infrared, etc.)/NASO	4	4	4	4	4
Ground-Based Astronomical Activities	All Disciplines	Not Applicable--No Launch Vehicle Requirements				

(a) See Planetary Exploration chapter.

RELEVANCY RATING:

5 Critically Relevant
4 Fundamentally Relevant
3 Advantageously Relevant
2 Conveniently Relevant
1 Remotely Relevant
0 No Apparent Relevancy

are not reproducible on Earth will advance efforts to control nuclear fusion for power generation, have potential for uncovering completely new applications in the nuclear science area, and possibly even for discovering new, more powerful energy sources..

From the technological viewpoint, numerous accomplished or planned NASA developments in the space astronomy area have military application potential. Two of the most important of these are, perhaps, (1) the defense possibilities associated with using the highly stabilized platforms such as those developed for the OSO, OAO, and X-15 aircraft, and (2) any significant development of satellite infrared astronomical observing techniques (either in the sensor or in cooling techniques) which could logically find valuable application to military surveillance, reconnaissance, and detection schemes operating in the infrared.

Other space astronomical developments likely to influence our military posture include the utilization of the large optical and radio telescopes currently being considered for space astronomy purposes in terrestrial reconnaissance roles. Also, the experience forthcoming from using man in astronomical observing and equipment repair and maintenance roles will be applicable to assessments regarding man's potential military role in space.

Education and Knowledge[5,6,9,16,26,37,40]

Since most objectives and, thus, most of the results of space astronomy endeavors are of a basic or fundamental research nature, the explicit benefits obtained thus far or anticipated fall into the general education and knowledge category. Because major discoveries are becoming so commonplace in contemporary astronomy (viz., the recent discovery of X-ray and radio stars, pulsars, and quasars), the anticipated role that space astronomy will play in explaining such discoveries accounts for the critical relevancy rating assigned to many automated astronomical activities in Table IV-2. Most of the specific types of data and/or knowledge sought and the scientific importance of these have been previously considered under each of the subprogram objective areas and will not be repeated here. Also, the impact of NASA activities in astronomical education facilities and graduate students is discussed at some length in the section on ground-based astronomical activities.

Space

A reliable indication of the general relevancy of space astronomy activities to our national space commitment can be determined by comparing the previously identified space astronomy goals and objectives with those quoted for (1) NASA space science goals in general, (2) overall national goals as stated in the 1958 Space Act, and (3) functional goals for space as designated by the Bureau of the Budget. Such comparison shows space astronomy activities apply to all three stated NASA space science goals:[3-6]

(1) To master the near-Earth (terrestrial) space environment
(2) To explore the solar system
(3) To improve understanding of the universe.

Although explicitly involved in nearly all eight objectives cited in the Space Act, space astronomy endeavors relate most specifically to the first named objective, which is to expand human knowledge of phenomena in the atmosphere and space.[5] Likewise, space astronomy contributes to all three space goals as designated by the Bureau of the Budget:[41]

(1) To improve our ability to operate in the space environment
(2) To advance man's knowledge of the universe
(3) To use the experience gained for man's benefit.

This close association between space astronomy and broad space goals accounts for the high relevancy rating assigned to the topical objective areas in Table IV-2. As in almost all objective categories, the relevancy of man-associated astronomical observations are difficult to assess. In most cases, such functions have been considered as being only conveniently relevant. The only exception being in the area of the National Astronomical Space Observatory (NASO) program, an area in which man's role is considered fundamentally relevant.

International Relations

In this so-called "Golden Age" of astronomy, significant discoveries are being reported from almost all countries throughout the world. This in itself is testimony of the international scope of contemporary astronomical science. Accordingly, U.S. astronomical activities and results in general, and space astronomy in particular are not only of national interest and importance but also are instrumental in promoting an image of U.S. scientific leadership, a position which is seriously and continuously under challenge by the U.S.S.R. Because of this close association, almost all NASA objectives and activities in this area have been considered advantageously relevant to this national goal.

The extent of U.S. dominance of international space astronomical activities is most clearly evinced in proceedings and writings of Commission 44 (Astronomical Observations From Outside the Terrestrial Atmosphere) of the International Astronomical Union. Also the international overtones of the growing trend to establish sophisticated astronomical observing facilities in the Southern Hemisphere should not be minimized, particularly in view of the growing interest to improve U.S.-South American relations.[23]

The U.S. has succeeded in dominating the field of space astronomy to date. This is not to say that the U.S.S.R. is without such interests and activities. Actually, the converse is true. That is, the Soviets have long been successfully engaged in rocket ultraviolet studies and have designed and launched balloons and satellite payloads specifically for making ultraviolet and X-ray observations of the Sun and stars. In several cases U.S.S.R. studies preceded U.S. endeavors. Indeed Cosmos 215, launched in April, 1968, represented the world's first successful orbiting astronomical observatory. They have frequently mentioned the value of locating astronomical observatories on the Moon, and the Crimean Astrophysical Observatory is reported to be involved in a project to design and construct a telescope for use on Soviet manned space stations.[29,43]

Several other countries have space astronomy activities, which are primarily a part of the European Space Research Organization (ESRO), and include the British study of the galactic magnetic field and the Dutch study of solar X-rays, both from orbiting satellites. Canadian researchers have plans to study galactic radio noise by means of receivers aboard the International Satellite for Ionospheric Studies (ISIS) series. Insofar as NASA's satellites are concerned the amount of foreign cooperation to date is quite small and the only case noted involved the planned British studies of solar X-rays from Orbiting Astronomical Observatories (OAO).[3]

From a cursory survey of NASA documents, it was possible to identify only two foreign institutions (one in Canada and one in Australia) which have contracts (both minor) with NASA. Thus, it appears that direct NASA cooperation with foreign countries in space astronomy up to now has been quite nominal. It is expected that this cooperation will increase with the culmination of NASA efforts to develop the National Astronomical Space Observatory (NASO). Accordingly, man-associated observatories of the NASO class have been rated somewhat higher (i.e., fundamentally relevant) than other activities because of the potential multination involvement.[2,3]

Natural Resources and Environment

In Reference 41, the Natural Resources and Environment functional field was defined as including the nonmilitary space research performed by the Atomic Energy Commission (AEC) and the Environmental Science Services Administration (ESSA). Although there exists some overlap with the AEC insofar as interests in background space radiation and in understanding nuclear processes occurring on the Sun and stars are concerned, the major relevancy of space astronomy objectives and activities is to ESSA. As can be seen in Table IV-2, this relevancy is estimated to vary between "conveniently relevant" in the case of most man-associated space astronomical activities to "fundamentally relevant" for solar astronomical activities.

The ratings result from the fact that ESSA maintains the nation's responsibility for describing, understanding, and predicting the state of the upper atmosphere and space environment; a responsibility being fulfilled primarily through its Space Disturbance Laboratory. However, as discussed at some length in the text, equal arguments for the value of long-term routine monitoring of the Sun for scientific as well as applied (forecasting) purposes can be offered. Therefore, such activities can profitably be pursued by both NASA and ESSA.[5,20,26,38]

An indirect relationship between NASA space astronomy activities and this national goal exists in the area of satellite survey of natural resources. For instance, highly stabilized aircraft and satellite platforms and sophisticated observing (ultraviolet, infrared, and visible) techniques developed for remote sensing of astronomical bodies in space can be "conveniently relevant" to technical requirements associated with the development of aircraft and satellite schemes for Earth-resource surveys.

Future Flight Program

Many of the initial space astronomy investigations have and, in many cases, are still being conducted aboard specially equipped balloons, aircraft, or vertical rockets. However, for the purpose of this study, interest in space astronomical flight programs is confined to those involving automated and manned satellites. To date, U.S. results have come from the multipurpose Explorer and Orbiting Geophysical Observatory (OGO) series with more recent and sophisticated observations being undertaken by the Orbiting Solar Observatories (OSO) and the Orbiting Astronomical Observatories (OAO). Also selected experiments of space astronomy interests are being conducted on the Interplanetary Monitoring Platform (IMP), the Applications Technology Satellites (ATS), and the new Explorer Sunblazer Series scheduled to begin in 1970. Table IV-3 shows the space astronomy payloads that have been more recently noted as funded, planned, or proposed for each of the subprogram objective areas along with the more pertinent launch features. As is obvious from the Table, future space astronomy payloads will range from the small automated satellites of the Explorer and Scout class (Radio Astronomy Explorer [RAE] and Small Astronomy Satellite [SAS]) to more of the sophisticated automated Orbiting Solar Observatories and Orbiting Astronomical Observatories. Current plans to introduce man into space astronomy include the Apollo Telescope Mount (ATM), the Astronomical Space Telescope Research Assembly (ASTRA), the Orbital Workshop Experiments (OWSE), and the Manned Astronomical Space Telescope (MAST). This interest in manned space astronomy activities is expected to culminate in the establishment of a fully-manned National Astronomical Space Observatory (NASO) sometime in the 1980's.[2,3,5-8,44-46]

TABLE IV-3. SPACE ASTRONOMY PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES[2,3,5-8,44-46]

Spacecraft or Satellite Series	*Prelaunch Designation*	Projected Launch Date	Payload size, inches and weight, lb	Orbital Features	Launch Vehicle	Launch Site	Mission and Miscellaneous Remarks
			Automated Astronomical Observatories				
Orbiting Astronomical Observatories (OAO)	OAO-B	1969	120 x 84 4500	Circular Orbit (417 n m)	Atlas-Centaur	ETR	To obtain moderate resolution spectra of astronomical objects in the ultraviolet region 1000 - 3500 Å
	OAO-C	1970	120 x 84 4500	"	"	ETR	To obtain high resolution spectra of hot stars and brighter planets in the 1000 - 3000 Å region
	OAO-D	1972	120 x 84 4436	"	"	ETR	To obtain moderate resolution spectra of a variety of stars in the 1000 - 3000 Å region for study of a wide variety of objects such as quasars and galactic nuclei, normal and peculiar stars, close binary stars, planets, and galactic nebulae This will be operated as a national facility to be used by a large number of astronomers.
	OAO-E	1974	120 x 84 4436	"	"	ETR	To conduct high-resolution ultraviolet spectrophotometry of bright stars and planets and moderate resolution spectrophotometry for faint astronomical objects. Possibly high resolution imagery in the wavelengths between 2000 - 7000 Å particularly of the planets
Orbiting Solar Observatories (OSO)	OSO-F	1969	38 x 44 641	Circular Orbit	Delta	ETR	To obtain high spectral resolution data from the pointed experiments within the range from approximately 1250 Å During a solar rotation, including raster scans of the solar disk in selected wavelengths
	OSO-G	1969	38 x 44 607	"	"	ETR	To observe the active physical processes of the sun by which the Sun influences the Earth and its space environment and to study the Sun's constitution and behavior
	OSO-H	1970	38 x 44 675	"	"	ETR	
	OSO-I	1972	38 x 44 607-675	"	"	ETR	To conduct solar minimum and quiescent solar studies of coronal structure, X-ray polarization effects, ultraviolet and X-ray spectra from localized (small) solar regions Exploration of hard X-ray spectrum will begin
	OSO-J	1973	38 x 44 607-675	"	"	ETR	
	OSO-K	1975	38 x 44 607-675	"	"	ETR	
	OSO-L and M (Replaced by *Helios*)	1977-1979	38 x 44 607-775	"	"	ETR	To study various types of solar activity, emphasizing good spectral, spatial, and time resolution and to conduct measurements during the increasing portion of the next solar activity cycles

TABLE IV-3. SPACE ASTRONOMY PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES[2,3,5-8,44-46] (Continued)

Spacecraft or Satellite Series	Prelaunch Designation	Projected Launch Date	Payload size, inches and weight, lb	Orbital Features	Launch Vehicle	Launch Site	Mission and Miscellaneous Remarks
				Automated Astronomical Observatories (Continued)			
Radio Astronomy Explorer (RAE)	RAE-B	1970	608	Circular Earth Orbit	Delta	WTR	To determine, as a function of frequency, the direction and intensity of celestial radio emissions blocked by the ionosphere using four 750 ft extendable antennas.
Small Astronomy Satellite (SAS)	SAS-A	1970	320	Circular Orbit (300 n. m)	Scout	San Marco	To conduct high sensitivity, high resolution, all-sky surveys for X-ray sources· search for temporal variations in X-ray source intensity over periods of minutes to months, and measure the angular diameter of X-ray sources, and identify those sources
	SAS-B	1971	320	"	"	San Marco	
	SAS-C,D	?	320	"	Scout	San Marco	To conduct broad surveys of stellar X-ray, gamma ray, and ultraviolet sources.
				Man-Associated Astronomical Observatories			
Apollo Telescope mount (ATM)	ATM-A	1971	--	Circular Orbit (>500 km)	Saturn IB	ETR	The first large manned astronomy mission, will carry five major solar experiments in the X-ray, ultraviolet and visible range
	ATM-B	1974	--	"	"	ETR	To determine size and structure of bright X-ray objects and to assist in determining the physical processes giving rise to this radiation.
	Solar ATM	1974-1975	--	"	"	ETR	To undertake detailed solar observations in the spectral range 1500-10,000 A as the new solar cycle begins
	High-Energy ATM	1977	--	"	"	ETR	Will be similar to ATM-B but with larger and improved X-ray detectors. In addition, it will carry a large area gamma-ray spark chamber
	Solar ATM	1978-1979	--	"	"	ETR	To obtain longtime observations of solar activity during next solar maximum. Will have larger telescope than on 1974-1975 ATM
	Solar ATM	1982-1983	--	"	"	ETR	To obtain extreme ultraviolet spectrographs and X-ray emissions having higher resolutions than on previous solar ATM's.

TABLE IV-3. SPACE ASTRONOMY PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES[2,3,5-8,44-46]
(Continued)

Spacecraft or Satellite Series	Prelaunch Designation	Projected Launch Date	Payload size, inches and weight, lb	Orbital Features	Launch Vehicle	Launch Site	Mission and Miscellaneous Remarks
				Man-Associated Astronomical Observatories (Continued)			
Orbital Workshop Experiments (OWSE)	OWSE	?	--	--	--	ETR	To perform small experiments in the ultraviolet or X-ray region and, infrared background surveys requiring cryogenics Also will use a Cerenkov counter for sky surveys in very high energy gamma rays.
Manned Astronomical Space Telescope (MAST)	MAST	?	--	--	--	--	To undertake detailed ultraviolet radiation measurements of extended astronomical sources using a man-operated 38-inch telescope.
Astronomical Space Telescope Research Assembly (ASTRA)	ASTRA	1978	--	Circular Orbit of About 300-350 n. m. Altitude	Atlas-Centaur	ETR	To perform very high resolution telescopic observations of the planets, stars, and galaxies with a set of large aperture optics and to exploit both automated and manned space technology to develop a first generation stellar observatory for manned operation and maintainability.
National Astronomical Space Observatory (NASO)	NASO	1981	--	Synchronous or Low Orbit	--	ETR	This manned national astronomical observatory will include improved instrumentation for observations of the Sun, planets, other members of the solar system, stars, interstellar gas and dust, normal and peculiar galaxies, unusual objects such as X-ray and radio stars, quasars, pulsars, and other objects hopefully still to be discovered.
				Ground-Based Observatories			
NO LAUNCH REQUIREMENTS							

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CHAPTER V. PLANETARY EXPLORATION

GOALS: To improve understanding of:

(1) The origin and evolution of the solar system

(2) The origin and evolution of life

(3) The dynamic processes that shape the terrestrial environment

RELATION OF PLANETARY EXPLORATION TO NATIONAL GOALS:

	NATIONAL (FUNCTIONAL) GOALS												
PROGRAM OBJECTIVE AREAS	EDUCATION & KNOWLEDGE	SPACE	NATIONAL SECURITY	VETERANS	LABOR & MANPOWER	WELFARE	HEALTH	COMMERCE, TRANSPORTATION, & COMMUNICATIONS	GENERAL GOVERNMENT	AGRICULTURE	NATURAL RESOURCES & ENVIRONMENT	HOUSING & COMMUNITY DEVELOPMENT	INTERNATIONAL RELATIONS
EARTH-BASED OBSERVATIONS	NOT APPLICABLE - NO LAUNCH VEHICLE REQUIREMENTS												
NEAR-EARTH OBSERVATIONS	●	●											●
AUTOMATED PLANETARY EXPLORATION	●	●					●			●	●		●
MANNED PLANETARY EXPLORATION	●	●					●			●			●

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CHAPTER V

PLANETARY EXPLORATION

G. E. Wukelic

Introduction

Since the early 1960's, the U.S. and the U.S.S.R. have enthusiastically participated in programs aimed at developing and launching automated payloads specifically designed for planetary missions. Both countries have recorded several significant space firsts and have experienced several frustrating disappointments as a consequence of their efforts to probe the planets directly. Although several of the planetary findings rank among the most significant obtained thus far in the space age, others, such as those associated with the Soviet Venera (Venus) probes remain a source of current scientific controversy.

That this phase of space research is in its infancy is obvious from the fact that all past efforts were confined to Mars and Venus, and most of the information or data obtained have been on the nature of the interplanetary medium rather than on the planets per se. However, the number, frequency, and expense of these planetary missions to date reflect the seriousness of both countries' interest in exploring the planets directly. The next decade will involve additional probes to Mars and Venus and, possibly, initial attempts to investigate several other planets of the solar system. Subsequently, other, more remote, planetary environs will be probed, as will several comets and asteroids. Man's role in planetary exploration remains uncertain although it appears likely that his schedule for initial involvement may be influenced by more than scientific considerations.

In the discussion that follows an attempt has been made to identify the broad goals and objectives currently postulated for this space program area. Several of the more significant objectives and interest areas associated with each of the planets and with comets and asteroids are briefly described. A brief discussion of the relation and relevancy of planetary exploration to national goals is included, as is a summary of the flight program possibilities for this area.

Goals and Objectives

The goals of the NASA planetary exploration program have been described most frequently as aimed at improving understanding of the following phenomena:

(1) The origin and evolution of the solar system

(2) The origin and evolution of life

(3) The dynamic processes that shape the terrestrial environment.

These goals were originally postulated in 1965 by the Space Science Board (SSB) of the National Academy of Sciences[1*] and endorsed by the President's Science Advisory Committee.[2] In June, 1968, the SSB reiterated them.[3]

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* Superscripts denote references cited at the end of this chapter.

They are accepted in the Memorandum of the Planetary Program prepared by the NASA Planetary Working Group (September 3, 1968)[4] and in the Memorandum for the Planning Panel Chairmen by Homer E. Newell, NASA Associate Administrator (January 8, 1969).[5] They are accordingly assumed to constitute the most authoritative as well as the most recent formulation of U.S. goals in planetary exploration. It is also assumed that they are, currently at least, considered to be of equal importance so that no concentration of effort is contemplated in the foreseeable future to pursue any of these goals at the expense of the others.

Most noticeable is that the goals, as formulated, are so broad as to exclude any explicit reference as to interest in the nature of the planets themselves. Also, the goals as stated suffer somewhat in overall consistency. The first two are indicative of purely scientific interest. To determine, for instance, that the solar system came into being by condensation of primeval matter, or that life existed on the surface of Mars two billion years ago, but became extinct sometime after that, would be of great scientific, philosophic, and, perhaps, even religious significance, but in practice such results might have little effect on present-day activities. The formulation of the third goal, however, is concerned with the application of planetary findings. Indeed, the SSB is insistent that the study of Mars has already significantly contributed to understanding Earth atmospheric processes.[3] Actually, as noted in the OSSA Memorandum for the Planetary Program[4], Goal 3 is being satisfied by planetary exploration conducted in pursuit of Goals 1 and 2.

Although attitudes are constantly changing, the goals leave open questions as to what restraints, if any, should be imposed on planetary exploration activities. Since September 13, 1959, when the Soviet Luna 2 made a crash landing on the Moon, both the U.S. and the U.S.S.R. have been launching probes to other bodies in the solar system with steadily increasing frequency. Some of these activities, including several which are now only under discussion, could lead to contamination of other planets' atmospheres and soil with terrestrial bacteria or to starting uncontrollable chemical reactions on their surface. It is the view of many scientists that such results are totally undesirable and, therefore, that these activities should be subjected to restrictive--but intelligent--controls. However, serious formal and informal proposals have been heard in scientific circles about the possibilities of modifying the atmosphere of Venus so as to make it more desirable from the terrestrial point of view, of using asteroids as space stations, of breaking up comets apparently just to see what would happen, and, finally--but certainly less seriously--with that planet made habitable, of transporting the excess population of the Earth to Venus. Attempts along some of these lines will undoubtedly be made either by the U.S. or by the Soviet Union.

Another topic which could logically be included in an overall declaration of planetary exploration goals is international cooperation. In particular, with the apparent similarity between U.S. and U.S.S.R. planetary exploration activities and interests, formal efforts should be directed toward establishing means to combine scientific, technological, and funding resources of both nations so as to ensure maximum return to mankind from a scientific venture having clearly no relevance to national security. Although no specifics in this regard are noted, the SSB in their report on Planetary Exploration 1968-1975[3] included the need to exploit international cooperative opportunities inherent in planetary exploration as one of their major recommendations. In that complete planetary exploration cooperation is highly unlikely, future cooperative planning efforts should emphasize the delineation of one or more specific planetary mission opportunities, such as those occurring only during the rare 1976-1980 solar-system alignment, for initial implementation of a joint program.

General Considerations

Planetary exploration in pursuit of the above designated goals may be conceived as consisting of several functional objective areas, each one representing an increase in cost by orders of magnitude.

(1) Earth-based planetary exploration

(2) Near-Earth planetary exploration

(3) Automated planetary exploration

(4) Manned planetary exploration.

Earth-Based Planetary Exploration. The broad objective here is to explore the planets from the surface of the Earth by all means that present-day technology is capable of providing. This implies constructing and financing the operation of observatories in favorable locations equipped with modern optical and radio telescopes and auxiliary apparatus, study, systematization, and publication of results, etc. The cost of this effort is infinitesimal in comparison with the whole of the NASA budget and that this effort should be pursued with greater vigor than is now in evidence is consistently recommended by the Space Science Board.[1] A continuous and sustained effort in this objective area ought to result in a steady expansion of planetary knowledge. The limitations of this mode of approach to planetology are due to the distances involved. Even the nearest planet (Venus) at its closest approach is still 25,000,000 miles away. Therefore, observational results on planets obtained from the Earth necessarily refer to the planet as a whole or to a very large part of its surface.

Near-Earth Planetary Exploration. This objective area involves placing the observing apparatus largely or completely outside the atmosphere of the Earth in high-altitude balloons, rockets, artificial satellites, and ultimately in orbiting manned space observatories. Such procedure opens great possibilities in the study of the regions of the spectrum which are not accessible on the surface of the Earth because of the interference of the terrestrial atmosphere, as well as in the utilization of the full resolving power of the telescope. Spectacular and scientifically important results have already been obtained this way in the study of the Sun, the discovery of X-ray stars, and in stellar physics in general. However, due to the low-surface brightness of the planets, contributions of this method to planetary physics have been insignificant to date and, moreover, the limitations of large distances are still present.

Automated Planetary Exploration. Automated probes to the vicinity of planets have already become reality for both Venus and Mars, with some remarkable results being obtained as to the existence or nonexistence of a magnetic field, shape of the planets, distribution of density in their interiors, etc. The amount of topographic information collected by flybys is meager, however, and many such flights are required for complete coverage since photographic coverage is for only a small part of the surface; in the case of Mars it is less than 1 percent. Placing artificial satellites around a planet would have greater potential for obtaining such important information. Also, soft-landing instruments on the surface of a planet, as has been achieved for the moon and, questionably, for Venus*, provides still another opportunity for this objective area.[1,2,6-10]

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* It seems now that the Soviet Venera 4, 5, and 6 probes ceased transmitting at some height above the surface of the planet rather than at the surface, as originally claimed.

This is as far as automated planetary exploration has gone up to the present time (May, 1969). Although numerous schemes for reconnoitering or roving on the lunar and planetary surfaces have been suggested from time to time, nothing concrete along these lines has been accomplished. Likewise, instruments and samples from the surface of a planet, the Moon included, have not yet been returned to the Earth. At the present time it seems likely that this will be the next step in the exploration of the Moon. The possibility of the return of an instrumented payload from the lunar surface and perhaps even from the vicinity of planets has been enthusiastically expressed in the Soviet Union following the successful recovery of the Zond 5 and Zond 6 circumlunar payloads.[11,12]

Manned Planetary Exploration. Manned exploration even of the Moon is still a debatable issue and all sorts of objections are continuously being voiced. So far as surfaces of other planets are concerned, manned exploration appears to be almost economically prohibitive, even for Mars. Yet it is doubtful that the problem of the existence of life on the Moon or Mars, at the present time or in the past, can be resolved without manned expeditions. The goals of planetary exploration as formulated by NASA would, therefore, require astronauts landing on the Moon and on Mars, the two places which are promising from the point of view of the existence of life (probably only in the past) and where landing is possible. However, NASA's overall official view continues to remain vague, and current planning documents are devoid of such considerations. In the past, NASA reports have been concerned with describing and/or modeling the planetary environments for use, if need be, in manned planetary vehicle design and development[13,14], and as noted in the recent Space Science Board report[3], several Office of Manned Space Flight (OMSF) studies and proposals support the view that the next major space goal should be a manned mission to Mars.

The Space Science Board[3] stated in June, 1968, that they were unable to identify a need in planetary exploration, in the foreseeable future, for the unique abilities of man and recommended accordingly that resources committed to this area be reallocated to unmanned planetary exploration. Subsequently, a NASA Planetary Program Memorandum[4] noted that initiation of manned planetary missions for the 1970's was not practical. The U.S.S.R., on the other hand, appears definitely to have manned exploration of the planets foremost in mind although no specific plans and/or dates for such exploration have been publicized.

The last stage of planetary exploration involves the activity of man on the surface of the Moon or planets, i.e., improvement of conditions for existing there, such as construction of shelters, survey and utilization of natural resources of the planet, establishment of means of communication with the Earth, etc. Such topics in reference to the Moon, asteroids, and to a lesser extent the planets, have been discussed in U.S. and foreign scientific and popular literature, but there is no evidence that they have been seriously considered except in association with manned lunar exploration.

A review of current activities, results obtained, and future research objectives and needs associated with both Earth-based and near-Earth planetary observations noted earlier in this chapter are contained in the Space Science Board reports[1,3], the 1967 report of the President's Science Advisory Committee[2], and to a lesser extent in the 1968 Memoranda for the NASA Planetary[4] and Astronomy[15] programs. These reports also discuss the relationship and/or interaction of these investigations to the overall planetary exploration program. Also, a brief overview of Earth-based and near-Earth planetary activities is presented in the space astronomy chapter. Because of the above coverage and expressed views regarding the lack of a current manned planetary exploration role[1,3,4], the discussion of planetary exploration objectives that follows has emphasized for the most part considerations regarding automated planetary exploration.

Planetary Exploration Objectives.

Turning now to the problem of discerning specific objectives in planetary exploration, there exists a remarkable disagreement among authorities as to how and what should be undertaken. In general, however, most NASA planning documents note that the principal objectives of the planetary program are to explore the nearby planets, to determine the physical properties of their atmospheres and surfaces, and to search for the existence of life.[4,9,10]

It may be maintained that any automated planetary flyby, orbiter, or lander will provide important information. The problem for the NASA planners, however, is how, with existing and projected technological means and within present financial constraints, to obtain the maximum information about each planet. This program requires, immediately, further specification of the projected missions, and a decision as to which planet(s) is (are) to be investigated first. Such planning considerations have been provided to NASA in the past by IIT Research Institute[16-26] and JPL[27-32].

Recalling the previously discussed set of goals in planetary exploration, it is obvious that they cannot be completely achieved by the investigation of any one planet; some of these goals must inevitably be preferred to others in the choice of a program. For instance, if the interest is in studies of the origin of the solar system, the most promising planet is Jupiter because it is thought to represent the matter of the primeval nebula out of which the solar system evolved. Saturn perhaps would be even better from this point of view as, in addition to having a composition similar to that of Jupiter, it is surrounded by a remarkable ring which may have important cosmogonical clues. However, Saturn is twice as far from the Earth as Jupiter, and therefore less accessible, and so initial efforts most logically must be directed at Jupiter.[1,3,4,10,16-23,28,30,32]

The most remarkable opportunity for the direct exploration of the outer planets occurs in 1977-1978, which permits a so-called "grand tour". With very little additional launch energy requirements, the flyby can pass Jupiter, Saturn, Uranus, and Neptune in succession.* Another favorable configuration of the planets to allow such a complete tour will not occur for more than a century. However, other multiple outer planetary probe possibilities for the rare solar system alignment existing between 1976-1980 have also been identified and all are currently under consideration by NASA.[4,21-23,32]

From the point of view of ascertaining the origin of life, which is another goal of planetary investigation formulated by NASA, major planets (with the possible exception of Jupiter[20]) are clearly unsuitable, since the chance of the existence of life there is infinitesimal. The best planet for this purpose is Mars, where life can be expected to exist or at least to have existed, in which case, fossil traces may remain. The probability of settling the question of extinct life on Mars or any other planet via automated probes is considered remote. On the Earth, fossils occur on the surface in only a few isolated locations, usually along courses of rivers where the process of denudation progresses sufficiently far. Even there, one has to look hard for loose samples of the type that could be picked up by some instrument aboard a lander. It is known that the Earth has had abundant life for billions of years but a random sample of its surface is not likely to reveal fossils.[26,33]

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* This mission takes advantage of the perturbation of spacecraft trajectories by the gravitational effects of the planets involved. Other planetary combinations are possible over an extended period.

To achieve the third goal of NASA, the clarification of the dynamic processes that shape the terrestrial environment, one had best study Venus, whose mighty atmosphere is subject to much more intense solar radiation than is the atmosphere of the Earth. Moreover, in view of the complete absence or very small intensity of the magnetic field of Venus, the solar corpuscular streams and galactic cosmic rays play an entirely different role in the planet's meteorology. If Venus, as seems likely, does not now have any organic life on its surface, or in its atmosphere, the existing conditions might contribute to the solution of the problem of how life on the surface of the Earth originated and why it did not become extinct long ago.[25,33]

However, the formulation of objectives does not wholly depend on established goals as the planets themselves, Earth included, cannot be manipulated. Since orbital periods are not commensurable, the most favorable, and therefore the least expensive, opportunities occur only seldom and they must be utilized if the maximum yield from planetary exploration is to be obtained. In addition to purely geometrical configurations, physical factors of the planets, and the state of solar activity should also be considered. For the study of the propagation of the wave of darkening on Mars, for instance, the Southern Hemisphere of Mars must be turned toward the Earth, and the orbiter must arrive there at the beginning of the Martian Spring. In the decade 1970-1980 this will occur only in 1971. The atmospheres of Jupiter and Venus should be studied during peak periods of solar activity. Many other examples of this nature could be quoted.[25-29,33]

Moreover, the character of the mission depends on what feature of the planet is to be studied most intensively. A number of schedules and the necessary equipment to achieve the objectives have been set up at various times. The priority for planetary exploration as noted originally by the Space Science Board in 1965 and since modified to reflect an increasing interest in the planet Mercury is as follows:[6,24]

(1) Mars
(2) Venus
(3) Jupiter
(4) Mercury
(5) Saturn
(6) Uranus
(7) Neptune
(8) Comets
(9) Asteroids
(10) Pluto.

A condensed chronological schedule of automated planetary missions as recently recommended by the National Academy of Sciences in 1968 for the next 5 years (1970-1975) is as follows:[3]

Year	Recommended Flights	Type of Mission
1970	Venus	Orbiter
1971	Mars	Orbiter
1971	Mars	Orbiter (Small)
1972	Venus	Orbiter
1973	Mars	Orbiter-Lander
1973	Mercury and Venus	Flyby
1973	Jupiter	Flyby
1975	Venus	Orbiter
1975	Mars	Orbiter-Lander
1975	Asteroid	Probe
1975	Comet	Probe

An overview of the major scientific objectives most frequently associated with each of the planets is shown in the matrix below. The subsequent discussion considers the objectives for each of the planets in greater detail.

Planetary Objective(s) Matrix[1,3,4,16-32]

Objective	Mercury	Venus	Mars	Jupiter	Other Planets
Exobiology		X	X		
Atmosphere	X	X	X	X	X
Topography	X	X	X		
Internal characteristics	X	X	X	X	
Solar/galactic flux	X	X	X	X	
Satellites			X	X	X
Thermal regime and sources of heat		X		X	
Energy balance		X	X	X	
Radio frequency emission				X	X
Details of planets, Jupiter's Red Spot, Saturn's Rings				X	X

Mars. The scientific objectives for the study of Mars have been worked out in great detail. The following contains a condensed version of a recent study by the Jet Propulsion Laboratory[27], with a few remarks.

It is pointed out in this study that one of the most important phenomena on Mars, the propagation of darkening (Wave of Darkening, WD) can be studied advantageously only in 1971 in the whole decade of 1970-1980. Therefore, its investigation should constitute the primary objective of this orbiter flight. To satisfy geometrical and physical conditions, the launch period should be between May 9 and 31, 1971, which will assure the arrival period at the planet Mars between November 19 and 26. The orbital life of the satellite should not be shorter than 90 days. For secondary objectives, practically all that might be learned about the planet without landing there is recommended: its topography, composition, atmosphere, exobiology, etc. The scheme is as follows:

Wave of Darkening. This is a complex phenomenon originating at both polar caps, but better seen in connection with the South Cap. This is the general progression of darkening spreading meridianally (that is, not through the existing dark formation such as canals) with a variable velocity, but on the average 35 km/day. From either cap the darkening spreads away from the pole and with the diminution of the cap itself it crosses the equator and dies out somewhere at 20° latitude in the opposite hemisphere. Occasionally, the wave of darkening from the South Cap has been traced to 40°N.[27]

There is another type of darkening which spreads along the existing dark channels in the vicinity of the South Polar Cap, such as Hellerpontus, with a much reduced velocity of 20 km/sec. There are also irregular darkenings of very considerable extent. Thus, in 1954 a new dark area northeast of Syrtis Major appeared as if overnight and occupied 2% of the planet's surface, that is, in relation to the Earth, covering an area of the continental United States. Much has been written about these phenomena, and one of the possible explanations is the spread of some kind of vegetation vitalized by the melting of polar caps.[34]

The JPL group recommends therefore a thorough study of the wave of darkening and clarification of its connection with a number of other phenomena in the atmosphere and on the surface of the planet. Among these are the following:[27]

(1) Decay of polar caps: the parallelism here with the wave of darkening is evident but the connection, if any, is not known

(2) General wind circulation

(3) Topography and its influence on the propagation of darkening

(4) Local atmospheric composition, especially the presence of water vapor derived from the melting caps

(5) Cloud phenomena

(6) Biological phenomena, as one of the possible explanations of the wave of darkening

(7) Change in the chemical composition, such as absorption of water vapor and change in color of certain regions

(8) Actual transfer of material such as water. This is considered by most investigators unlikely on account of scarcity of water in the polar caps.

Topography. As Mariner 4 in 1965 photographed less than 1% of the surface of Mars but, nevertheless, established the existence of heretofore unsuspected formations on its surface it is anticipated that future flights will be even more successful in the unravelling of Martian secrets. In respect to topography the following objective areas can be cited:[27]

(1) Craters and mountain ranges. Mariner 4 photographed more than 70 craters with diameters between 4 km and 120 km. If these photographs represent a typical sample of the Martian surface, some 10,000 craters with diameters of more than 4 km can be expected on the surface of Mars.

(2) Slopes and elevations, the presence of which is certain but the magnitude of which can hardly be fixed from terrestrial observations. Altitudes of Martian formations up to 5 km are probable

(3) Dark and light areas

(4) Canals

(5) Polar caps, their nature, extent, and variation.

Atmosphere. The importance of this study is obvious if instrumented or, ultimately, manned descent to the surface of Mars is contemplated. It is now agreed that the Martian atmosphere is extremely rarefied, but the actual pressure of the atmosphere of Mars on its surface is not certain; various methods give widely discrepant results. The atmosphere, thin as it may be, nevertheless is capable of producing occasional clouds and more or less permanent haze layers. The following objective areas of study can be distinguished:[27]

(1) Composition

(2) Origin of constitutent gases

(3) Interaction with the polar caps

(4) Temperature variations, with height and latitude

(5) Exosphere

(6) Colored haze

(7) Clouds

(8) Circulation.

Planetology. Celestial mechanics make it possible to determine the total mass of the planet and, therefore, its average density. These data must further be supplemented with studies that are not possible from the surface of the Earth:[27]

(1) Internal mass distribution

(2) Exact shape of the planet

(3) Thermal regime and its history

(4) Composition of the surface--physical and chemical

(5) Satellite data--density, surface, composition, etc.

Biology. Perhaps the greatest contribution to science that the proposed flights can make will be on the subject of the possible existence of life on Mars, although the final solution of this problem will probably have to wait for a landing on the surface of the planet. The program for study is as follows:[27]

(1) Presence of living organisms

(2) Best sites for possible presence of living organisms in preparation for subsequent landing

(3) Presence of water: permafrost, local vapor concentation, liquid water, etc.

(4) Trace constituents in the atmosphere which may be of importance from the biological point of view

(5) Diurnal variation of atmospheric constituents

(6) Photochemical reaction products

(7) Radiation flux at the surface of the planet

(8) Mineralogy--soluble ions, hydration water, etc.

Venus. Venus is often referred to as the "twin of the Earth" but it appears that this appellation is true only in respect to its size. The atmosphere of Venus, and consequently physical conditions on its surface are totally different from those of the Earth.

Since Venus has no satellite its mass is imperfectly known. Here, however, is a specific example of a mystery, the solution of which may lie in the methods of space science. Up to about 1900, Venus was repeatedly observed with a satellite. Several dozen observations of this kind are in existence and not all of them can be reasonably explained by the imperfection of the telescope, an observational error taking a star for the satellite, or plain invention. Since in recent times this satellite has never been observed, although assiduously looked for, this enigma continues to remain.[35]

Space science has already made some contributions regarding the distance and mass of Venus but not a great deal has been learned about the physical conditions on the planet. This is primarily due to the fact that the atmosphere of Venus is so extensive and dense that the surface topography of the planet remains almost totally unknown, and only more or less educated guesses have been offered regarding its gross features as revealed in visual, photographic and radar observations. The U.S. Mariner 2 passed Venus within 35,000 kilometers on December 14, 1962, and Mariner 5 on October 19, 1967, within 4,000 kilometers of its surface. Two days before the last date, the Soviet probe Venera 4 reportedly delivered an instrumented package to the surface. A comparison of the American and Soviet results shows that very little is settled by such brief observations, and even the data which were previously considered well established may now be open to question.[25,36,37]

Atmosphere. These sources agree that CO_2, the presence of which in the atmosphere of Venus has been known for 40 years, is the main constituent, and not a minor ingredient, as had been supposed by some investigators. The Venera 4 recorded the abundance of CO_2 between 90 to 95% of the total atmosphere. The rest of the atmosphere is presumably nitrogen for which Venera 4 gas analyzers indicated an upper limit of 7%. The Mariner 5 data indicate the abundance of CO_2 from 87 to 92% depending on other ingredients, in the first case nitrogen, in the second argon.

The Venera 4 results also indicate the presence of water in the atmosphere of Venus, but in very small quantities from 0.1 to 0.7%. Venus is thus a very dry planet, and it is very difficult to explain why it should be so. The absence of water also complicates the problem of explaining the clouds on Venus.

In addition to this there is some question at what level the Soviet instrument package ceased to transmit. This happened very abruptly and various explanations were offered: either it was smashed touching the surface, or imploded because of the higher than anticipated atmospheric pressure.

Thus, little has been settled by these Venus probes, and further attempts along these lines are warranted.

Interior. That Venus has no intense magnetic field comparable in strength to that of the Earth has been known for some time. According to the Mariner 5 data the strength of the Venusian magnetic field is certainly less than 1% of the field of the Earth, and probably does not exceed 0.1%. The Venera 4 measurements indicate a strength of only 0.03%. Here is another remarkable discrepancy between the twin planets Earth and Venus. It is known that the terrestrial magnetic field fluctuates in strength, and sometimes disappears altogether with an estimated period of some thousands of years. Perhaps Venus is at the present time in one of its stages when the magnetic field nearly disappears before reversing its sign. Another explanation is that short-period fluctuations are involved and another measurement may show a sizable field. Perhaps, also the slow rotation of Venus is responsible for the absence of the magnetic field even though its interior is metallic, as is the Earth's case. Only further measurements can answer these questions.

Temperature. The high temperature of Venus has been established by radio methods but it was not known to what level these determinations were applicable. The data from Venera 4 and Mariner 5 do not agree at all, although both show high temperatures. The Venera 4 results indicate the temperature at the surface of Venus 550 K. The Mariner data, if extrapolated to the surface would give 700 K. This discrepancy would disappear if Venera 4 measurements were assumed to refer not to the surface of the planet but to a height 20 kilometers above it; but other explanations have also been suggested.

Mercury. Mercury is one of the most attractive objects for investigation among the planets. This is because practically nothing is known about its surface or other physical parameters, and any contribution made by NASA to this subject is likely to be significant. This is particularly so since further progress in the elucidation of its mysteries by Earth-based observations is not likely.[24,33]

Being the innermost planet the conditions for its observations are even more unfavorable than for Venus. Mercury is a small body, its diameter being only 0.38 of the diameter of the Earth. Therefore, its apparent disk as seen from the Earth under the most favorable conditions (when the planet is at its inferior conjunction, or seen more or less against the Sun's disk) does not exceed 12" (seconds of an arc). Taking the best compromise between the apparent size of the disk and its phase (about 70 degrees) the disk of the planet as usually seen is a mere 6" (seconds) in diameter. Under such conditions, 1" (second) (the usual limit of the resolving power of telescopes) corresponds on the surface of Mercury to 800 kilometers or 600 miles.[24,33]

Moreover, Mercury never appears on a dark sky, since at its most favorable elongation it is only 27 degrees away from the Sun. Although the planet may reach apparent magnitude considerably brighter than Sirius (i.e., $-1^{m}.7$), this occurs when it is on the other side of the Sun near the superior conjunction, and can hardly be observed.[33]

Observational conditions of Mercury are therefore so poor that the data based on visual observations by the most competent astronomers are fragmentary and contradictory. Since it does not have a satellite, its mass and therefore its density are imperfectly known. The density is estimated to be very close to that of the Earth, and may even exceed it so that Mercury may be the densest planet in the solar system, and its linear size may be exceeded by Ganymede, the largest satellite of Jupiter.[33]

In view of the proximity of Mercury to the Sun--and consequent high temperature, and its small mass it should not have any atmosphere, yet visual and photographic observations suggest phenomena on its surface that may be best described as dust storms, i.e., occasional veiling of its surface features as on Mars.[33]

The markings on Mercury are at best on the limit of telescopic visibilities and, moreover, they can be observed only when the planet is near its elongations, introducing therefore a selectivity effect. Until quite recently the period of Mercury's rotation was accepted to be exactly equal to the period of its revolution around the Sun, i.e., about 88 days as established by Schiaparelli as early as 1890. Contemporary radar observations indicate a period of about 59 days, and it appears to be exactly equal to two-thirds of its orbital period or 58.646 days.[33] The shorter period has been recently confirmed by photographic observations[38] and is favored by dynamical considerations, yet it is too early to accept it without reservation. The longer period was just as convincingly demonstrated by photographic observations prior to the radar results. It seems, however, that Mercury's rotation period bears a simple relationship to its orbital period, but the value of, say, one-third rather than two-thirds of the orbital period is not excluded.[33]

Other observations suggest that the surface of Mercury is very much like the surface of the Moon, yet its density is almost twice as high as the Moon's density, indicating a different mode of formation. A comparison of Mercury-Moon is treated in great detail in a recent study by D. Morrison[39], which concludes that the superficial layers of the Moon and Mercury must be very similar.

The data on Mercury that can be gathered by a flyby probe may be grouped into several categories:

Topography. Since no details have been seen on Mercury less than the minimum diameter 600 kilometers, the resolving power of the flyby cameras even of 60 kilometers will probably reveal structures of great interest. Since the variation of the brightness of Mercury with phase is like that of the Moon, results could indicate that Mercury has craters and formations characteristic of the Moon. If the flyby goes near enough to the surface of the planet (say 10,000 miles or so) results of the greatest importance to planetary astronomy can be expected.[24,33]

In the Orbital Astronomy Support Facility Study[40] a plan for photographing Mercury is indicated. Since the distance factor remains the same for the orbital observatory, the image of Mercury remains small, on the average 7" (seconds) in diameter, and with the proposed photographic instrumentation, the photographed image will be only 1 or 2 millimeters across. Even with the resolving power of the camera 0.12 (seconds), surface features smaller than 50 kilometers or 30 miles will not be discernible. The unfortunate aspect of this proposal is that the angular proximity of Mercury and the Sun is not affected, and it is necessary to plan for some 3,000 photographs during the observation period of some 8 months.

Atmosphere. Although a dense atmosphere around Mercury is considered impossible both on theoretical grounds and from the data of its transits of the Sun, the presence of a thin, perpetually renewed atmosphere of CO_2 or argon is not excluded. The latter may be produced by the outgassing of its surface rocks under the influence of the solar wind and short wavelength radiation. CO_2 has been reported as being observed in the spectrum of Mercury, but never decisively confirmed and is perhaps a temporary phenomenon, if present at all. Anomalous polarization, which may be explained by light scattering in a thin atmosphere, has also been observed from time to time.[41]

The Orbital Astronomy Support Facility Study[40] also proposed a spectroscopic investigation of Mercury along with other planets. The advantage over similar Earth-based observations consists solely in the ability to record the ultraviolet and infrared parts of the spectrum. But the distance factor is essentially unaffected, and it is doubtful that the orbital observatory will furnish spectra of any details on the planet's surface.

Temperature of the Surface. The temperature of Mercury's surface must vary within wide limits, from nearly absolute zero on its unilluminated side to about 400 C in the subsolar point, enough to melt tin or lead. This temperature depends not only on the distance from the subsolar point but also on the position of Mercury in its orbit. Because of the high orbital eccentricity (0.206, the highest among the planets), Mercury is some 17,000,000 miles nearer the Sun at perihelion and receives twice as much radiation than it does at aphelion.[24,33]

Indirect determination of Mercury's temperature from the surface of the Earth is affected by the absorption in the Earth's atmosphere as well as by geometrical restrictions, as Mercury can be observed only at its greatest elongations from the Sun. Nevertheless, these studies indicate the average temperature of Mercury's surface to be very high, although somewhat lower than estimates based on theoretical considerations.[24,33]

Dynamic Parameters. Since Mercury has no satellites its mass cannot be determined exactly, and even its diameter is uncertain because of the difficulties of observing it in the proximity of the Sun. This makes Mercury's density uncertain, and, of course, nothing is known about the distribution of mass in its interior, the flattening of its spheroid, position of its rotational axis, magnetic field, etc. All these data can possibly be obtained by a spacecraft flyby.[24,33]

Jupiter. Jupiter is the largest planet in the solar system, eleven times as large as the Earth in diameter and more than 300 times its mass. Owing to its great distance from the Earth (more than four astronomical units at the nearest, that is at opposition), its apparent disk never exceeds 50" (seconds). Since the actual resolving power for Earth-based telescopes is about 1" (second), the smallest details usually seen on Jupiter's disk are about 1,700 to 1,800 miles in diameter. Thus, knowledge of Jupiter is based almost solely on a study of very large formations on its visible disk.[16,33,42]

It has long been established that what appears to be a solid surface of Jupiter is really its atmosphere in perpetual motion so that noticeable changes in it may be sometimes seen within 20 minutes. The eye or photographic plate, or any instrument used for observation, can penetrate this atmosphere only to a certain depth, determined by the nature of the instrument used and the physical status of the atmosphere. On succeeding nights astronomers see different configurations in the atmosphere of Jupiter, yet there are some definite regularities determined by the physical properties of the planet and, perhaps, by solar activity. Some of these regularities are baffling from the point of view of terrestrial meteorology.[16,33,42]

The most mysterious phenomenon is undoubtedly the Great Red Spot, an oval of dark red color in the Southern Hemisphere of Jupiter. It is something like 30,000 miles long in longitude and 7,000 miles in latitude, but its dimensions, shape and color are subject to change. It was first noticed in 1878 when it became very prominent, and perhaps may have been observed in 1831. With less certainty, it can be connected with the great spot observed and described by Robert Hooke in 1664-1672. Even though definitely an atmospheric phenomenon, with a noticeable drift both in longitude and latitude, it has been in existence for at least 140 years, and perhaps even 300 years. The Red Spot is simply the most conspicuous formation in Jupiter's background. Many smaller spots, both darker and lighter than the general background have been observed, some of them persisting for years.[16,33]

Another enigma of Jupiter is the continuous change in the coloration of details seemingly in a periodic fashion. Several authorities find a 11.08 year period for these changes corresponding to the main period of the solar cycle, others think that these changes are irregular. Many fanciful explanations have been advanced for this phenomenon, including the existence of complex organic molecules in the atmosphere of the planet, but none of them have been generally accepted. In the same connection are probably changes in the apparent brightness of Jupiter amounting to 0.4 amplitude and found by some observers to be following the sunspot cycle.[42]

Finally, the remarkable activity of Jupiter in the radiowave portion of the spectrum must be mentioned. This is a complex phenomenon consisting of at least three components with different wavelengths and intensities. From this fact, and other radio observations the existence of very extensive and strong ionized belts around Jupiter has been postulated, analogous to the Van Allen belts around the Earth.[16,33]

The contributions that direct exploration by NASA can make to knowledge of Jupiter can be considered under several categories:

Topography and Atmosphere. These two topics for Jupiter merge into one, as what is seen on its surface is in actuality part of its atmosphere. The presence of large quantities of ammonia (NH_3) and methane (CH_4) in its atmosphere had been established by spectroscopic observations some 40 years ago. It is clear, however, from other observations as well as from theory that NH_3 and CH_4 are really minor constituents, and the bulk of the atmosphere must consist of much lighter gases, such as hydrogen and helium. However, the ratio of abundances of these gases is unknown and now subject to dispute. All sorts of ratios have been proposed, the most acceptable ratios for H/He vary from 3 to 1/3. There may, of course, be other gases in small amounts.[16,33]

The desirability of learning more about Jupiter's atmosphere derives from the conviction that it represents the original atmosphere of all planets, including that of Earth, where it became modified by a chemical evolution during the pre-life stage under the influence of solar radiation and oceanic water squeezed out of the interior. By observing Jupiter from a space platform[40] it may be possible to identify further the constituents in its asmosphere, since the lines or bands of its atmosphere are in the ultraviolet or infrared portion of the spectrum, which is almost totally absorbed by the Earth's atmosphere. But the results thus obtained will necessarily refer to the whole planet, or to a very sizable portion of it rather than to details such as various spots. In other words, really important information about Jupiter can be expected only from a probe passing fairly near its surface, say within 10,000 miles but, in view of the great mass of the planet this will be a difficult task.[16-18,33]

Internal Structure. It is now thought that Jupiter is actually a much smaller planet than it appears to be. It has a core about four times the diameter of the Earth, surrounded by a tremendous layer of ice, consisting of water and other substances. The details of this model are disputed, and most likely Jupiter's internal structure will not be known with any degree of certainty until a probe returns information about its atmosphere and gravitational field.[16-18,33]

Radiation Belts. Jupiter appears to be unusually well supplied with radiation belts and is, in fact, the only other planet besides the Earth to have them. They are estimated to be enormous--several hundred times as strong as those of the Earth. Any further information on them is desirable. This, however, is another area to which Earth-based radio observatories can contribute substantially.[16-18,33]

Satellites. Jupiter has 12 known natural satellites, all of which are small except the four discovered by Galileo. These are enormous bodies of the size comparable to the Earth's Moon, and two of them are larger than the Moon. The satellite JIII (Ganymede) may even exceed Mercury in size. Owing to the great distance, very little is known about these bodies which approach planetary size. Some details have been seen on their surface from time to time but observers do not agree as to their significance or even their existence. A probe going through this satellite system undoubtedly will obtain valuable information about these enigmatic bodies.[19,33] The SSB of the National Academy of Sciences recommends a flyby of the Pioneer type in 1972 or 1973 with photography of the planet and its satellites at 10 kilometers resolution, along with other instruments for the complete study of the planet.[3]

Other Planets. The possibility of launching probes to Jupiter as well as to the other outer planets Saturn, Uranus, Neptune and Pluto is currently of major planning interest because of the unique planetary alignment that will occur during the 1976-1980 period. In addition to the four-planet "Grand Tour" mission (1977-1978) which would go by Jupiter to Saturn, Uranus, and Neptune, taking advantage of the gravitational forces involved, other multiple outer planetary flyby possibilities are being considered. Several publications are available which identify existing mission opportunities and associated scientific objectives. The precise number and mix of missions to be selected, however, will depend on a combination of scientific objectives, mission environment, launch vehicle performance and funding considerations.[16-23,32,33]

<u>Comets and Asteroids</u>. Comets and asteroids are considered sometimes as debris of the solar system and sometimes as remnants of primordial matter that never condensed into planets. In either case they are of great astronomical interest from the standpoint of the origin and nature of the solar system but conditions for their intercept and investigation are very unfavorable. Several analyses of specific mission possibilities, however, have been performed.[44-50]

Comets differ greatly in brightness and size, and the most conspicuous representatives of this class of celestial bodies come unannounced in nearly parabolic orbits. The time between the discovery of a comet and its perihelion passage, when it is the brightest, is usually a few weeks or months. In other words, there is not enough time to prepare for a direct investigation of a comet that is likely to become bright.[33,49]

Among comets with shorter periods, there are few of sufficient size and brightness to warrant serious efforts and plans for investigation. One is the famous Halley's Comet which passed perihelion in 1910 and is due again at perihelion in about 1986. In its last appearance it was first observed about half a year before perihelion, but with modern techniques this time may be extended perhaps to 2 years. Therefore, planners have some 15 years to consider a Halley's comet mission. At the present time the year 1984 seems fairly remote, and the evolution of space technique is so rapid, that it is hardly worth while to make any formal planning decisions about Halley's Comet for several years.[33]

There are some 100 comets with periods shorter than 75 years, but all of them are small and faint bodies. Comet Encke, with the shortest known period of only 3-1/2 years, is often mentioned in connection with a possible "comet probe or flyby", as is Comet D'Arrest.[4,49] A D'Arrest mission in 1976 has been judged as the best cometary mission between 1965-1986.[46] Concern has been expressed as to the value to be derived from such probes, unless they can be returned to the Earth with a sample of cometary material. The latter appears doubtful, based on present-day space technology.[33]

Objectives most frequently cited for direct, cometary investigations from spacecraft relate to studying the composition and physical state of typical comets, cometary dynamics, and the interaction between the solar wind and comets. There have also been discussions of creating an artificial comet, i.e., releasing in space, material characteristic of the composition of the nucleus of a comet. This should include ice of CO_2, NH_3, H_2O, etc. Its behavior could be studied from Earth-based stations with the advantage of knowing its exact composition.[43-50] Something similar has already been done both in the U.S. and U.S.S.R. by releasing sodium clouds from cosmic probes.[43,51] Also, the orbiting space observatories discussed in the space astronomy chapter might contribute to the study of comets by extending their spectra to the ultraviolet and infrared regions, as is being done in the case of other celestial bodies.[40]

Asteroids are now thought to be fragments of a planet which existed between Mars and Jupiter and was broken up by collisions or some other unknown cause. They begin as bodies several hundred kilometers in size and range, for observable asteroids, to about 5 kilometers in diameter. There is no reason why there should not be even smaller bodies in the asteroidal belt but they cannot be photographed by even the most powerful telescopes unless they develop a highly eccentric orbit and pass near the Earth. Such was the case of asteroid Icarus which went by the Earth in June, 1968, at a distance of 4,000,000 miles and the diameter of which was measured by radar to be only 0.6 kilometer.[52]

Smaller and smaller asteroids should merge into large meteorites but there are enough misgivings about this simple scheme to make a sample of an asteroid very desirable. However, this appears to be out of reach of space techniques, at least for another decade. Objectives most frequently cited in connection with asteroids relate to defining the distribution of matter in the asteroid belt and determining the surface features, densities, and rotation periods of typical asteroids. Planning reports have discerned several candidate asteroid flyby missions including the Icarus, Eros, and the two largest asteroids--Ceres and Vesta but any serious program along these lines, considering current budgetary constraints, seems unlikely.[4,53-57]

Relation to National Goals

Few research assignments are as delicate as one which requires estimating national importance or utility of a scientific endeavor so fundamental as planetary exploration. Out of 13 previously designated functional national fields or goals[58], it is certain that planetary exploration endeavors are producing new discoveries and findings quite important to national education and knowledge interest as well as being prerequisite to the achievement of several space goal commitments. In addition, several indirect benefits or applications of knowledge or techniques developed in association with planetary exploration activities can be cited for the functional national goals of health, agriculture, and natural resources and environment. And, lastly, that such activities have international significance is clearly manifest following each major U.S. or U.S.S.R. planetary exploration accomplishment.

A subjective estimate of the relative relevancy (based on a 0 to 5 rating scale) of each planetary exploration objective category (i.e., near-Earth, automated, and manned exploration) to each of these six goals is shown in Table V-1. A brief discussion summarizing the basis of the relevancy ratings follows. Because of their remoteness, no effort was made to associate planetary exploration objectives to the remaining seven functional national goals. Principal information sources utilized in the preparation of the following discussion include references.[1-4,9,10,15,51,58-65]

Education and Knowledge

Space exploration in a short interval of 11 years has clearly demonstrated how little man has learned about the universe by staying on the surface of the Earth, where he is separated from the great Cosmos by a thick, obscuring atmosphere. Such space age findings as the craters on the surface of Mars rank with the greatest discoveries made with the telescope during the preceding 300 years. Because of the potential that the various modes of planetary exploration contain for adding significantly to existing knowledge of the solar system and universe, most objective areas have been considered to range from fundamentally to critically relevant to the education and knowledge national goal.

The specific knowledge requirements sought from each of the planets and which may be obtainable via planetary probes have been previously considered. In addition to this shopping list of identifiable needs for each of the planets, it must be noted that it is principally the challenge of the unknown that has been the motivating force in man's attempt to penetrate the mysteries of the universe since the time of Galileo. Also, caution must be exercised in evaluating the potential of purely scientific objectives in that most major discoveries in science were unforeseen and unpremeditated and were unexpected consequences of research undertaken for an entirely different purpose, sometimes even of pure chance. Often ultimate applications of discoveries were very far removed from the interests of the discoverer. Who could have foreseen, for instance, that Roentgen's annoyance with his photographic plates becoming fogged and his desire to trace the source of this interference would result in the discovery of X-rays and a revolution in medicine and surgery? In astronomy there are many examples of unforeseen and unintended discoveries. The search for stellar parallax in the 18th Century, for instance, resulted in fundamental discoveries of the aberration of light and nutation, both of great importance in contemporary astronomy and yet having nothing to do with the primary purpose of investigation. In planetary astronomy itself there are many examples of such unexpected windfalls. In 1781, William Herschel studying the structure of the Milky Way accidentally came across the planet Uranus. The discovery of another major planet in the solar system was so unexpected that Herschel announced it as a peculiar kind of comet, and would not admit it was a planet until further observations conclusively showed its nearly circular heliocentric orbit.

TABLE V-1. ESTIMATE OF THE RELEVANCY OF PLANETARY EXPLORATION OBJECTIVES TO NATIONAL GOALS

		National (Functional) Goals					
Program Objective Areas	Planetary Objectives	Education and Knowledge	Space	International Relations	Health	Natural Resources and Environment	Agriculture
Earth-Based	All Planets	Not Applicable--No Launch Vehicles Involved					
Near-Earth	All Planets	3	3	3	0	0	0
Automated	Mars	4	5	4	3	2	3
	Venus	4	5	4	1	2	1
	Mercury	5	4	3	1	2	1
	Jupiter	4	5	3	1	2	0
	Other Planets	4	5	3	1	2	0
	Comets and Asteroids	5	3	3	0	0	0
Manned[(a)]	Mars-Venus	4	5	3	1	0	1

(a) No formal program in existence.

RELEVANCY RATING:

5	Critically Relevant	2	Conveniently Relevant
4	Fundamentally Relevant	1	Remotely Relevant
3	Advantageously Relevant	0	No Apparent Relevancy

Although many astronomical findings seem to affect everyday life but little, everyone certainly realizes that it does make a difference whether there are many inhabited planets or just one, whether there exists intelligent life elsewhere in the universe or if it has developed only on the Earth, and whether life on the Earth has existed four billion years or only 6,000. Answers to such problems are immediately connected with religion which is so basic as to concern itself with the meaning of life on Earth and the cosmic status of man, and religion has been a powerful historical and sociological force ever since man became a rational creature. This is evident throughout human history in Galileo's conflict with the Catholic church or in the attempts of British protestant scholars in the 17th and 18th centuries to reconcile the Bible and new astronomy. It is evident even today in persistent and largely ineffectual efforts of Soviet propagandists to use astronomical data to combat religion.

Space

The high relevancy rating assigned to almost all planetary exploration categories in Table V-1 is because of the similarity among planetary exploration goals and those postulated for space science activities in general, the NASA Space Act, and the space functional field goals as cited by the Bureau of the Budget. Most appropriate parallelisms relate to the proclaimed interest in improving understanding of the origin and evolution of the solar system and life, matters to which direct planetary exploration could hold the key. Documentation for the "critically relevant" ratings assigned to most automated planetary exploration objective areas is contained in the previous discussion. The discussion also identifies the limitations associated with near-Earth planetary observing, which accounts for its substantially lower rating. Although man's role in planetary exploration is not clear, the fact that it is extremely doubtful that the problem of the existence of life on Mars, at the present time or in the past, can be resolved without a manned expedition, accounts for the critical rating assigned to manned planetary exploration in Table V-1.

International Relations

Planetary exploration relates to this national goal in two ways. One is fairly indirect and involves the enhancement of the U.S. scientific and technical image around the world, the other entails U.S. involvment in cooperative international scientific programs.

Insofar as the first association is concerned, both the U.S. and U.S.S.R. have exhibited, in the short history of the space age, impressive commitments to planetary exploration. And, although the U.S. has met with more technical success and accordingly has posted more planetary physics advances, the seriousness and consistency of Soviet planetary exploration efforts are sobering. Further, the Soviet program is inspired by political as well as scientific aims (viz, the depositing of Soviet flags, emblems, and banners on the planets) which suggest that the Soviets have no intention of withdrawing from planetary exploration contention. Rather, recent Soviet claims of the possibility of returning payloads from the vicinity of planets combined with their long-standing, consistently expressed desire to undertake manned exploration of the planets pose a serious challenge to the ability of the U.S. to maintain a leading role in this area of space endeavor.

Although a major item of concern to international prestige, planetary exploration to date has not inspired much international cooperation. Actually, even though all U.S. planetary probe findings are shared with the scientific community the world over, joint programs such as have evolved in other space-science areas are almost totally lacking in planetary exploration. Specifically, in connection with cooperation between the U.S. and U.S.S.R., the Space Science Board recommended in their July, 1968, report on planetary exploration that a coordinated effort be made involving representation of NASA, the Department of State, and the National Academy of Sciences, with the purpose of informally contacting knowledgeable Soviet scientists in regard to the possibility of joint planning of planetary exploration.

In view of the previous discussion, most areas of planetary exploration have been assessed as being at least "advantageously" relevant to our best interest in the field of international relations. Because of the priority effort envisioned and the potential scientific significance of such investigation; Mars and Venus objectives have been considered as being "fundamentally" relevant to this fundamental field.

Health

One planetary exploration goal specifically relates to the origin and evolution of life in the solar system. The possibility of detecting and studying life forms elsewhere in space which have been exposed to totally different environmental conditions could have far-reaching impact on health problems here on Earth. Possibilities suggested so far relate to the treatment of disease and the problems of aging. Also, techniques developed for detecting and preserving extraterrestrial life are considered applicable to microbiological assay techniques in medicine as well as to terrestrial contamination and sterilization problems.

Because most exobiological activities relate to exploration of Mars, it is the only planetary objective area that has been assessed as being "advantageously" relevant to this national goal. Other planetary exploration areas are estimated to be only "remotely" relevant.

Natural Resources and Environment

Most automated planetary exploration areas have been estimated to be "conveniently" relevant to the natural resources and environment functional field. Although several publications have implied that planets may possess exploitable and valuable natural resources, the relevancy rating here is based solely on the potential application of the compact, sensitive, and versatile equipment being developed for planetary exploration to terrestrial (geophysical) exploration principally for exploring remote and inaccessible areas of the Earth.

Agriculture

Although mostly of a spin-off nature, planetary exploration endeavors have been associated with several potential agricultural applications. For example, efforts to develop sterile spacecraft for planetary investigations will contribute improved methods of sterilization that reportedly can be applied to the canning industry. Increased knowledge about organisms growing in extreme environments, obtained in connection with studies associated with Martian exploration objectives, should have practical application for food storage and preservation. Because of these potential applications, automated efforts to explore Mars have been considered "advantageously" relevant to our national agricultural interest.

Future Flight Program

As noted in the September, 1968, NASA planetary program memorandum, over 700 potential planetary missions can be identified for the next decade alone. However, after eliminating those considered unrealistic for either technical or scientific reasons, the most promising missions reduce to something less than 50. Further considerations involving efforts to reduce duplication of missions, to incorporate smaller cheaper payloads (viz, Planetary Explorers), and to use a mixture of orbiting and lander spacecraft (several having multiple planet missions) results in a much smaller number. Current NASA plans show that planetary priorities continue to relate to Mars and Venus with Jupiter, Mercury, and possibly the other planets (via Grand Tour potentialities) receiving initial, but less extensive, exploration. The types of planetary flights that have been more recently noted as funded, planned, or proposed for each of the planets and for several comets and asteroids, along with the more pertinent associated launch features and mission objectives, are shown in Table V-2.

TABLE V-2. PLANETARY PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES[3,4,6,10,66-72]

Planet and Vehicle Type	Prelaunch Designation	Projected Launch Date	Payload size, inches and Weight, lb	Launch Vehicle	Launch Site	Mission Objective(s) and Miscellaneous Comments
			Automated Planetary Flights			
Mars						
Mariners						
Orbiters	Mariner Mars '71 (2)[a]	1971	--	Atlas/Centaur	ETR	To provide broad topographic and thermal coverage of Mars; to observe seasonal variations in the atmosphere and on the surface, and to make long-term dynamic observations.
Vikings						
Orbiter/Lander	Viking or Titan/Mars '73 (2)	1973	--	Titan/Centaur	ETR	To obtain data on Martian atmosphere and surface with emphasis on information relevant to life on Mars.
Planetary Explorers						
Orbiters	Planetary Explorer B	1973	50	Thor/Delta	ETR	To undertake sensitive particles and field measurements in vicinity of Mars.
	Planetary Explorer E	1975	50	Thor/Delta		
Saturn-Type (?)						
Landers	Hard and Soft Landers	1975	5-10,000	Saturn V	ETR	Surface laboratories for detailed surveys of Martian topography and environment. Later versions could include capability to return soil samples to Earth.
		1977	10-20,000	Saturn V/Nerva	ETR	
		1979	10-20,000	Saturn V/Nerva	ETR	
Venus						
Pioneer						
Orbiter	Pioneer E	1970	140-160	Delta (DSV-3L)	ETR	Modification could convert Pioneer E scheduled for 1969 to a Venus orbiter for extended particle and field measurements in the vicinity of Venus.
Mariners (?)						
Flyby/Probe	Venus Flyby	1972	1050	Atlas/Centaur	ETR	To investigate the cloud composition and determine temperature, pressure, and composition profile with particular emphasis on the lower atmosphere.
	Venus Flyby	1973	1300	Atlas/Centaur		
	Venus Flyby	1975	1300	Atlas/Centaur		
Orbiter/Hard Lander	Venus Hard Lander	1975				To monitor atmosphere during descent and to measure the physical environment on the surface of Venus.
Orbiter	Venus Orbiter	1976, 1978	2000	Atlas/Centaur	ETR	To produce high-resolution radar maps of surface of Venus.
Planetary Explorers						
Orbiters	Planetary Explorer A	1972	50	Thor/Delta	ETR	To undertake sensitive particles and field measurements in the vicinity of Venus.
	Planetary Explorer C	1973	50	Thor/Delta	ETR	
	Planetary Explorer D	1975	50	Thor/Delta	ETR	

(a) Number of flights.

TABLE V-2. PLANETARY PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES[3,4,6,10,66-72]
(Continued)

Planet and Vehicle Type	Prelaunch Designation	Projected Launch Date	Payload size, inches and Weight, lb	Launch Vehicle	Launch Site	Mission Objective(s) and Miscellaneous Comments
			Automated Planetary Flights (Continued)			
Venus/Mercury						
Mariner Mercury Flyby with Venus Probe	Venus/Mercury Flyby	1973	1300	Atlas/Centaur	ETR	To further investigate the atmosphere and surface of Venus and subsequently, to directly observe Mercury's atmosphere and surface characteristics for the first time.
Jupiter						
Mariner Flyby	Jupiter Flyby Jupiter Flyby Jupiter Flyby	1974 1977 1978	50-100 50-100 50-100	Titan IIID/Centaur Titan IIID/Centaur Titan IIID/Centaur	ETR	To undertake comprehensive measurements of the atmosphere and surface of Jupiter, including TV imaging and spectrometric analysis.
Pioneer Flyby	Pioneer F	1972	140-160	Delta (DSV-3L)	ETR	To measure particles, fields, and radio emissions while spacecraft is in the vicinity of Jupiter.
Multiple Outer Planet Flyby						
(Grand Tour-Jupiter, Saturn, Uranus & Neptune)	Possibly 2 missions (?)	1977, 1978	-- --	--	--	To probe the environments of all outer planets except Pluto by exploiting unique planetary alignments which make successive swingby maneuvers at each planet possible. (Grand Tour)
Other Possibilities	?	1976-1980	--	--	--	All outer planets
Comets						
Mariner Comet Flybys	D'Arrest Flyby	1976	800	Atlas/Centaur	ETR	The objective for the first comet intercept mission will be to investigate the comet at close proximity with experiments designed to determine its physical state, structure, composition, and how it reacts to its environment. Other important mission objectives will be to develop the technology and provide the cometary environmental information which will be required for succeeding missions. Experiments to be carried out include TV, mass spectrometry, solid particles, magnetic fields, plasma, and infrared or ultraviolet spectroscopy.
	Encke Flyby	1980	800	Titan IIIC/Centaur	ETR	To obtain *in situ* data on composition and temperature of the comet coma and tail.

TABLE V-2. PLANETARY PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES[3,4,6,10,66-72]
(Continued)

Planet and Vehicle Type	Prelaunch Designation	Projected Launch Date	Payload size, inches and Weight, lb	Launch Vehicle	Launch Site	Mission Objective(s) and Miscellaneous Comments
			Automated Planetary Flights (Continued)			
Asteroids						
Mariner Asteroid Flybys	Icarus Flyby	1977, 1978	800	Atlas/Centaur	ETR	To determine size, mass, surface properties of each of the asteroids and nature of the environment in vicinity of each.
	Eros Flyby	1979	800	Atlas/Centaur	ETR	
	Vesta Flyby	1974 (?)	--	Titan IIIC/Centaur	ETR	
	Ceres Flyby	1976 (?)	--	Titan IIIC/Centaur	ETR	
			Interplanetary Flights			
			See Space Physics Chapter			
			Near-Earth Planetary Flights			
			See Space Astronomy Chapter			

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CHAPTER VI. SPACE BIOLOGY

GOALS: To gain new fundamental biological knowledge by using space flight as a research tool

To develop a fundamental, coherent, and unifying biological theory of life, incorporating the important role played by gravity and time in life processes and structure

RELATION OF SPACE BIOLOGY TO NATIONAL GOALS:

PROGRAM OBJECTIVE AREAS	EDUCATION & KNOWLEDGE	SPACE	NATIONAL SECURITY	VETERANS	LABOR & MANPOWER	WELFARE	HEALTH	COMMERCE, TRANSPORTATION, & COMMUNICATIONS	GENERAL GOVERNMENT	AGRICULTURE	NATURAL RESOURCES & ENVIRONMENT	HOUSING & COMMUNITY DEVELOPMENT	INTERNATIONAL RELATIONS
SPACE EFFECTS	●	●	●				●	●		●			●
EXTRA TERRESTRIAL LIFE	●	●	●				●	●		●			●
LONG-DURATION MANNED SPACE FLIGHTS	●	●	●				●	●					●

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SPACE BIOLOGY

R. A. Wright

Introduction

The activation of the U.S. Space Biology program began with NASA's origin; however, originally the program was designed only to assure man's safety in space flight and was not concerned with other broader objectives. Fortunately, no problems were encountered in the manned program which could not be bypassed completely or resolved. The Russians took a different view and began basic research in space biology (primarily using dogs) prior to the time they launched man into space. They obtained a large volume of biomedical information from both manned and unmanned space flights. Although the United States sent a few primates on suborbital flights before man ventured into space, it was not until 1966 that a specially designed biosatellite payload was rocketed into orbit. Unfortunately, owing to deorbiting engine failure, the satellite payload was not recovered.

It is of great scientific interest to have a tool permitting living organisms to be studied in an abnormal or controlled environment. Biological studies under space conditions offer unique opportunities to learn more about the adaptations of living organisms to new and hostile environments. Thus, biological studies in space may improve understanding as to why certain organisms adapt to specific environmental condition and others do not. Such understanding can lead to new methods of disease control and prevention as well as to the development of new approaches in treating certain health problems. A better understanding of general physiological processes is important in itself. For example, an organism exposed to radiation under weightless conditions may respond quite differently than when it is exposed under 1 g on Earth. This knowledge will certainly be important in planning future manned space flight and may be important in problems involving radiation on Earth.

After they were formulated on a broader (than manned flight) basis, Space Biology programs have undergone frequent modification due to changing scientific, political, economic, and social considerations; however, these have represented changes in priorities rather than deviations from basic NASA objectives. This chapter identifies and relates the goals and objectives of the NASA Space Biology Program to broad national goals.

Goals and Objectives

Biology has emerged from a descriptive to a quantitative science only relatively recently but still lacks the general supporting theory characteristic of the physical sciences. The ability to conduct studies in unique, new environmental situations removed from terrestrial influences aids significantly in obtaining the required theory and understanding.

The broad goal of the Space Biology Program is to gain new fundamental biological knowledge by using space flight as a research tool.[1*] A more specific goal has recently been expressed relating to developing a fundamental, coherent, and unifying biological theory of life, incorporating the important roles played by gravity and time in life processes and structures.[2] Attainment of these goals will result in major advances in biological theory and methodology and will undoubtedly find application in medicine,

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* Superscripts denote references cited at end of this chapter.

public health, and agriculture, as well as in the continuing space effort. Specifically, there exists a need for new and better understanding of life processes. The urgency of this need is evident from national and world preoccupation with biological problems, such as food supply, overpopulation, disease, and pollution. The space biology program offers unique and, heretofore, unavailable opportunities to obtain increased understanding and knowledge with which to attack these problems.[2]

The most significant characteristics of life are the capacities of living organisms to maintain a uniform internal environment in the face of altered external conditions, to modify the environment to the advantage of the organism, and/or to adapt genetically to improve the probability of survival. There is a complicated interrelationship between basic biological functions and the environment. The space biology program will exploit the space environment to study the biological effects of weightlessness for prolonged periods, of weightlessness combined with radiation, of high-energy particle radiation, and of removal of organisms from geophysical periodicities associated with the Earth's rotation.[1]

As evidence of the importance of these activities, the President's Scientific Advisory Committee (PSAC) in 1967 stated "NASA should proceed vigorously with basic bio-science programs in biosatellites... In addition to its fundamental value, this information could be important to our understanding and solutions of problems of manned flight".[3] The National Academy of Sciences, Space Science Board, 1965, stated, "NASA should exploit special features of the space environment as unique situations for the general analysis of the organism-environment relationships... NASA should support studies in ground-based and in orbiting laboratories (biosatellites)... This should be considered a major responsibility of NASA".[3]

Program Objectives

The space biology program is seeking to achieve the foregoing goals through activities identified with the following three objectives:

(1) Determine Effect of Space on Living Organisms (Including Man)

(2) Seek and Study Extraterrestrial Life

(3) Support Long-Duration Manned Space Flights.

The subobjectives generally associated with each of these are.[2]

- To determine the effects of the space environment on Earth organisms, including man.

  (1) Survey biological effects of weightlessness in Earth orbit on the physiology, morphology, and behavior of various organisms including primates, rats, invertebrate animals, plants and single-cell organisms

  (2) Survey the effects on biorhythms, by removal from Earth's periodicity, on organisms including rodents, insects, plants, and single-cell organisms by Earth and solar orbital space flight

  (3) Survey effects of weightlessness combined with controlled radiation in Earth orbital flight on various organisms.

- To determine the location, origin, nature, and level of development of extraterrestrial life.

    (1) Develop fundamental theories and theoretical models relative to the origin and development of life

    (2) Develop techniques to collect and analyze extraterrestrial samples for possible living matter

    (3) Learn to distinguish between biologically produced organic matter and nonbiological compounds.

- To develop information in support of long-duration manned space flight.

    (1) Understand the action of gravity as an environmental factor and the role it plays in the origin, nature, and function of highly organized life

    (2) Investigate further in an attempt to understand why bone demineralization occurs under weightless conditions

    (3) Understand the influence of chronic acceleration on human health, such as a limitation of fat deposition

    (4) Understand why radiation protection is enhanced by hypothermic conditions

    (5) Investigate why certain bacteria grow under unnatural conditions and whether they are pathogenic to man

    (6) Investigate changes in sensorimotor coordination in space

    (7) Develop information on sleep and eye movement during sleep important for space flight, as well as for the normal Earth environment.

Relation to National Goals

To determine the long-range importance of research in space biology, an effort has been made to estimate subjectively the relevancy of each of the previously identified NASA space biology objectives to 13 functional national goals.[4] A quantitative estimate of the relevancy of space biology objectives to these national goals is shown in Table VI-1.

Following are examples of the specific benefits from space biology activities which have already been or are expected to be realized. These have formed the basis for determining the relevancy ratings assigned in Table VI-1.

National Security

The development of sensitive microbic detection methods for the space effort may be valuable for use in biological warfare detection. Animals used to study chemical and biological agents for warfare purposes may react differently if exposed to similar agents in a weightless state.[5] These findings should enhance our understanding of phenomena associated with these agents to aid in developing defensive measures against them.

TABLE VI-1. ESTIMATE OF THE RELEVANCY OF SPACE BIOLOGY OBJECTIVES TO NATIONAL GOALS

Space Biology Program Objective Areas	Subprogram Objectives	National Functional Goals: National Security	Education & Knowledge	Commerce Transportation Communications	Agriculture	Space	Health	International Relations
Effect of Space on Living Organisms (including man)	Weightlessness	4	3	2	2	5	3	2
	Biorhythms	4	5	2	4	5	3	4
	Radiation	4	3	2	2	5	3	4
Extraterrestrial Life	Theories and Model Development	0	5	0	2	2	4	4
	Detection	0	3	0	2	5	2	3
	Recognition	0	3	0	2	5	2	3
Long-Duration Manned Space Flights	Understand Gravity Effects	4	3	2	0	5	2	2
	Study Known Effects Such as Bone Demineralization	4	3	2	0	5	3	2
	Effects of Acceleration on Fat Deposition	4	3	2	0	5	3	2
	Why Hypothermia Protects Against Radiation	4	3	2	0	5	3	0
	Why Bacteria Grow in Unnatural Environments	3	2	2	0	5	3	0
	Eye Movements During Sleep	2	2	2	0	4	2	0
	Sensorimotor Coordination in Space	3	2	2	0	4	2	0

Relevancy Rating:
- 5 Critically Relevant
- 4 Fundamentally Relevant
- 3 Advantageously Relevant
- 2 Conveniently Relevant
- 1 Remotely Relevant
- 0 No apparent Relevancy

Improvements in existing measurement techniques, development of new techniques, and equipment miniaturization are only a few of the recognized benefits from space biology research which can directly affect our future military posture. As man learns to withstand long-term space flights, he may be able to improve reconnaissance techniques, develop new methods for delivering retaliatory weapons from spacecraft, develop new and better methods for performing space tracking, detection, and surveillance functions, and provide for better weather forecasting, communications, and navigation capabilities, so important in military operations.[5]

Control of space itself depends upon man's ability to adapt to and live and work in space. Space Biology research can provide the basic knowledge of physiological and psychological effects of space flight necessary to success in this endeavor. These are prerequisites to success in the development and operation of orbiting space stations and laboratories. There is no clear approach to evaluation of the importance of space control in continuing international cold- and hot-conflicts; however, it is clear that, if such control proves to be important, the winner (or leader) will be that nation developing the earliest and/or most thorough space biology program.

International Relations

As in other fields of science, the increase in basic knowledge and the practical achievements from space biology endeavors will enhance our prestige in international relations. The ability to speak and act with authority and confidence in terms of space bioscience will improve our image in all areas of bioscience.[5] The more fundamental space biology items and those of concern to a broader population were given a uniformly higher rating in this evaluation process.

Health

Several significant findings in space biology are now or can be expected to affect techniques and attitudes in the field of health. For example, the discovery that certain organisms are protected against radiation by hypothermia may be useful in reducing tissue damage from radiation therapy in humans.[2] Studies of astronaut cardiorascular system reactions in a weightless state and following return to a 1-g Earth environment have led to incorporating special exercises, in manned flights, to overcome orthostatic hypotension. These results may be useful in prescribing care for bedridden patients or those recovering from long inactive confinements. Other useful developments include miniaturized electronic and other apparatuses, such as the pacemaker used in treating diseased hearts, which can be implanted temporarily in the human body. Some of this instrumentation should be useful for telemetry and physiological monitoring in hospitals of the future, for diagnosis and treatment of illnesses. Clearly, more definitive information on the effects of interrupting or interferring with the biorythmic cycle will provide an understanding and, perhaps, a treatment for those now being affected by significant changes in time zones over a short period of time.

Although many convenient and advantageous relevancies could be found between space biology objectives and future national health services,perhaps the most significant (fundamental) relationship will ultimately be associated with the development of a unifying theory of life. Although it does not now appear critical , such a basic model may become of supreme importance to man at some time in the future.

Space

It was considered that the development of the unified theory of life is only conveniently relevant to the space program--although the successful development of such a model through NASA could serve as the springboard for more intense space activity. Based on the assumption that man's role in space will continue to expand, all other objectives of the space biology program were considered as critically relevant to the space function.

In view of past failure to encounter any insurmountable problems, this might be considered an over inflated evaluation; however, as the duration of manned missions continues to increase, basic biological information becomes of greater importance.

Education and Knowledge

The relevance ratings of various elements of space bioscience program to the fields of health, national security and space are indicative of the potential value to future education and general knowledge. The space biology program provides the first opportunity to gain basic information concerning the significance of the biorythmic cycle. Similarly, this program affords a unique opportunity to seek realistic models describing life processes. These were considered as critically relevant to the important long-term function of acquiring basic knowledge and disseminating it through the education process so that it may later be applied in resolving human medical and other problems. All other objectives were rated as either conveniently or advantageously relevant since the results will be primarily useful to support of manned space flight which, in turn, will provide more detailed information to the store of human knowledge.

Commerce, Transportation, and Communications

Space biology research should have importance in applications to problems which will be encountered with high-speed transportation. With the supersonic transport only few years off, problems due to human reaction to acceleration, deceleration, interuption of biorhythms due to rapid changes of time zones, and many other adverse effects must be resolved. If proven practical, Earth point-to-point rocket transportation systems will also present many hazards and problems of a biomedical nature which must also be resolved.

Agriculture

Some space biology developments have and will continue to be at least conveniently important to agriculture. Better understanding of plant and animal growth mechanisms derived from behavior under controlled space-flight conditions may reveal new ideas for food production on Earth. Of particular interest are the effect from interference with the biorhthmic cycle. Food preparation and packaging schemes are being improved as a result of advances made in connection with manned space flight requirements. Several other space biology items which may have applications to the field of agriculture are listed below.[5]

- Sterilization methods for spacecraft could improve the commercial canning industry.

- The missions which are being prepared for detecting extraterrestrial life are concerned with psychrophilic and helophytic bacteria and other organisms which can grow in abnormal conditions. The knowledge gained from this research will be important in preservation of cooked, dried, or salted foods.

- Research is under way on the synthesis of new antimetalistites, which can result in new techniques for killing plant and animal disease and pest forms.

- Weightless studies on various organisms will show the effect of gravity on cell growth and differentiation. Results could lead to an increase in agricultural production through better understanding of these processes.

Future Flight Program

Currently planned biosatellite experiments are designed to study biological functions at the cellular, tissue, organ, and organism levels in a wide variety of plants and animals. Phenomena to be studied at the cellular and tissue levels include biochemical reactions, genetic changes, embryologic development, growth and integrated functions. It is also planned that physiological function, behavior, and performance be monitored in more highly developed organisms such as primates during the biosatellite series. These biosatellite studies would provide many opportunities for critical testing of major biological hypotheses in the areas of genetics, developmental biology, environmental physiology, and general metabolism.

In the present biosatellite configuration, the major investment has already been made for engineering design, tooling, education, and documentation. Thus, it appears that continued cost-effective experimentation could best be accomplished from now on by flying more satellites of the same design which may be altered as needed to accommodate different experiments. However, to fulfill stated program objectives through the next 20 years, the investment in a larger spacecraft may be justified.[6] The larger biosatellite program would be intended as a companion to the life-sciences experimental opportunities offered by the manned space program. NASA appears to consider the larger improved biosatellite to be both economically and scientifically acceptable for the long-term coordinated program.

Projected launch dates and specific features of the biosatellite series are given in Table VI-2. These dates are meaningful only if approval is obtained for the program to continue. At the present time, only the Block I experiments have been approved.[6]

TABLE VI-2. SPACE-BIOLOGY PAYLOAD POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES[6]

Spacecraft Series	Proposed Launch Date	Payload	Orbital Features	Launch Vehicle	Mission Objectives
Block I Biosatellites C	1970	Rodents, Plants	150-200 n.m	Thor/Delta	Biorhythms, plant morphogenesis
D	1969	Monkeys	Circular	Thor/Delta	CNS, Cardiovascular
E	1971	Rodents, Plants	Circular	Thor/Delta	Biorhythms, plant morphogenesis
F	1969	Monkeys	Circular	Thor/Delta	Calcium loss from bone
Follow-on Biosatellite Series	1973	Primates, plants rodents	Circular	Thor/Delta	Continuation of Block I Satellite experiments
Improved Biosatellite	Late 1970's	Primates, plants rodents	Circular	Thor/Delta	Extended orbital flights
Advanced Biosatellite	1975	Primate	3-6 month extended Circular	?	2 gas system required.
Biopioneer	1973	Various	1 year in orbit Circular	?	Long term orbital effects
Bioexplorer	1972	Rodents	Circular 2-5 days	Scout	Biorhythms
Biotechnology Laboratory	1975	Humans, plants, animals	Circular continuous	?	Facilities available for many types of studies.

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CHAPTER VII. COMMUNICATIONS SATELLITES

GOALS: To study requirements for and technically assess the applicability of satellites to meet future communications needs

To insure that new technology is available when needed

To fulfill responsibilities assigned to NASA in the Communications Satellite Act of 1962

RELATION OF COMMUNICATIONS SATELLITES TO NATIONAL GOALS:

	PROGRAM OBJECTIVE AREAS	NATIONAL (FUNCTIONAL) GOALS: EDUCATION & KNOWLEDGE	SPACE	NATIONAL SECURITY	VETERANS	LABOR & MANPOWER	WELFARE	HEALTH	COMMERCE, TRANSPORTATION, & COMMUNICATIONS	GENERAL GOVERNMENT	AGRICULTURE	NATURAL RESOURCES & ENVIRONMENT	HOUSING & COMMUNITY DEVELOPMENT	INTERNATIONAL RELATIONS
POINT TO POINT	LARGE USER POINT-TO-POINT (FIXED)	●	●	●					●	●				●
	SMALL USER POINT-TO-POINT MULTIPLE ACCESS (MOBILE)	●	●	●					●	●				●
BROADCAST	BROADCAST - VOICE TO SMALL USER	●	●	●					●	●				●
	BROADCAST - TV TO BROADCAST CENTER	●	●	●					●	●				●
	BROADCAST - TV TO MODIFIED RECEIVER	●	●	●					●	●				●
	BROADCAST - TV TO UNMODIFIED RECEIVER	●	●	●					●	●				●

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CHAPTER VII

COMMUNICATIONS SATELLITES

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Introduction

Space communications programs can serve national goals in two areas. The first includes the various commercial, social, defense, and other similar applications for communications satellites. The second is communications support for the space program in general. In this Chapter, emphasis is placed on applications, specifically communications satellites. Information on the publicized objectives of the communications satellite program has been obtained from a number of authoritative sources and these objectives are listed in Table VII-1. Some of the factors that affect the priorities which could be assigned to the various communications satellite objectives are discussed, and anticipated costs of the various communications satellite services are examined. Technological and political considerations which affect the communications satellite programs are reviewed. Finally, NASA's role in the implementation of the different classes of communications satellites is considered.

Goals and Objectives

Authoritative statements on communications satellite objectives are available from a wide variety of sources including NASA documents, symposium records, legislation, and other publications which express considered opinions. A representative set of these goals and objectives is listed here for easy reference in Table VII-1. This Table includes a column showing "Practicality" as reasonable, sophisticated, or ultra-sophisticated, as well as a "Time Period" for implementation of the particular communications satellite. These columns are intended to reflect only technological factors and not political, social, or other considerations. For example, Item 18, "Satellite TV Education to Serve India's 560,000 Villages", is shown as reasonable in the 1970-74 time period as far as technological considerations are concerned. However, in a country that now has less than 1000 TV sets, only two transmitting stations and with a population dispersion of 90% of the people living in villages with fewer than 500 persons, considerable concern has been expressed that the in-place infrastructure necessary to utilize satellite Educational TV (ETV) (i.e., television sets, installers, repairmen) may take considerably longer to develop. Since the objectives listed in Table VII-1 tend to overlap, Table VII-2, "Composite Summary of Communications Satellite Programs and Objectives", is arranged to summarize the objectives in a manner related to systems (or services) and associated activities. The communications satellite goals and objectives in Table VII-2 can be associated with the following classes of service:

- Point to point, large user
- Point to point, small user, multiple access
- Broadcast, voice
- Broadcast, TV to rebroadcast centers
- Broadcast, TV to modified home receivers
- Broadcast, TV to unmodified home receivers.

TABLE VII-1. MULTIPLE SOURCE LISTING OF COMMUNICATIONS SATELLITE OBJECTIVES

	Publicized Goal or Objective	Time Period	Practicality	Reference
(1)	Provide capability for small terminal multiple access operations (i.e., aircraft, ships at sea, small emergency load vehicles	1970-1972	Reasonable	2
(2)	Provide capability for aural transmission directly to shortwave and FM radios and possibly TV receivers, and for TV transmission to community and educational facilities	1971-1973	Reasonable	2
(3)	Provide capability for TV transmission to individual receivers. Capability to be augmented by fringe area antennas and possibly pre-amps	1974-1975	Reasonable	2
(4)	Provide capability for TV transmission to individual receivers over wide areas or multiple channels over limited areas	1980-1986	Ultra-sophisticated	2
(5)	Provide educational TV at low cost	1974-1975	Reasonable	3
(6)	Provide voice broadcasts to developed and underdeveloped regions of the world	1970-1972	Reasonable	4
(7)	Provide TV service (one or more channels) to regions that do not have such service	1970-1975	Reasonable	5
(8)	Provide integrated tactical communications, navigation, and identification worldwide for Air Force planes	1970-1975	Sophisticated	6-8
(9)	Provide international air traffic control and communications	1970-1973	Sophisticated	9,10

TABLE VII-1. MULTIPLE SOURCE LISTING OF COMMUNICATIONS SATELLITE OBJECTIVES (Continued)

	Publicized Goal or Objective	Time Period	Practicality	Reference
(10)	"One of the corporations first tasks should be to study the practicality and the economic advantages of using communications satellites to establish an educational television and radio network. To assist the corporation, I am directing the administrator of the National Aeronautics and Space Administration and the Secretary of Health, Education and Welfare to conduct experiments on the requirements for such a system and for instructional television, in cooperation with other interested agencies of the government and private sector". - President Johnson recommending that Congress enact a Public Television Act of 1967.	1970-1980	Reasonable	11
(11)	"I believe the time has come to stake another claim in the name of all the people, based upon the combined resources of communications. I believe the time has come to enlist the computer and the satellite, as well as television and radio, and to enlist them in the cause of education". - President Johnson signing the bill establishing the Corporation for Public Broadcasting on November 7, 1967.	1970-1980	Reasonable	11
(12)	"But we must also improve the lives of children already born in the villages, towns, and cities on this earth. And they can be taught by the great teachers through the miracle of satellite television--and we are going to bring to bear every resource of mind and technology to make this dream come true". - President Johnson's Fifth State of the Union Message, January 17, 1968.	1970-1980	Reasonable	11
(13)	"To study the requirements for and technically assess the applications of satellites for future communication needs".	Continuing	Reasonable	11

TABLE VII-1. MULTIPLE SOURCE LISTING OF COMMUNICATIONS SATELLITE OBJECTIVES
(Continued)

	Publicized Goal or Objective	Time Period	Practicality	Reference
(14)	To insure that new technology to establish future communications systems is available when ready	Continuing	Reasonable	11
(15)	To provide consultation and advice to other agencies on technical matters	Continuing	Reasonable	11
(16)	To fulfill responsibilities assigned to NASA in the Communications Satellite Act of 1962	Continuing	Reasonable	11
(17)	Provide tactical and strategic military communications, short and long term	1968-1972	Reasonable	12-14
(18)	Satellite TV Education System to service India's 560,000 villages	1970-1974	Reasonable	15, 28
	<u>Specific Related Programs</u>			
(19)	Improved Frequency Utilization Program Noise Measurement Interference Experiments Spectrum Investigation below 1 GHz above 10 GHz Orbital Spacing Limitations Support to U.S. on International Telecommunications Matters.	Continuing	Reasonable	11

TABLE VII-1. MULTIPLE SOURCE LISTING OF COMMUNICATIONS SATELLITE OBJECTIVES (Continued)

Publicized Goal or Objective	Time Period	Practicality	Reference
(20) Small User/Multiple Access Communication Program Modulation Techniques TDM (Relay II Experiment 1) FDM SSB/PM Demand Assignment Multiple Ocean Technique Multiple Beam Antenna Development	1971-1973	Reasonable	11
(21) Space Broadcasting Program Voice Broadcast Satellite Mission Studies TV Broadcast Satellite Mission Studies Technology Investigations Joint NASA/INCOSPAR Study Group on TV Experiment Technical Consultation and Assistance to President's Task Force on Communications HEW, FCC, STATE, UAIA, OTM, Corporation for Public Broadcasting and Congress of the U.S.	1971-1985	Sophisticated	11

TABLE VII-2. COMPOSITE SUMMARY OF COMMUNICATIONS SATELLITE OBJECTIVES AND PROGRAMS

Description	Item Number, Table VII-1
Systems or Services	
Point to Point	
Large user, fixed	(13), (15), (16)
Small user, multiple access	(1), (8), (9), (13), (14), (17), (20)
Broadcast	
Voice to small user	(2), (6), (11), (12), (19), (21)
TV to rebroadcast Centers	(4), (5), (7), (10-13), (18)
TV to modified receiver	(3), (5), (7), (10-12), (18)
TV to unmodified receiver	(4), (7), (10-12)
Related Program and Objectives	
Technology Development	(13), (14), (16), (19-21)
Social, Cultural, and Political Objectives	(10), (15), (16), (21)

Before defining the six classes of service, it is useful to note that these goals are not exclusive to the U.S. Nearly all nations have applications for communications satellites which fit under one of the six classes above. Indeed, the U.S.S.R. has already initiated communications satellite TV broadcasts to rebroadcast centers, and other nations are actively planning various types of regional service which will contribute to satisfaction of their national goals.[1*]

Point-to-Point Communications

Large User Fixed Communications. Point-to-point, large user communications satellite systems provide communications links, via communications satellites, between high traffic points on the Earth's surface. The required technology has already been established for this type of service. This type of communications satellite system has been the first application of space technology and is the first to reach commercial operational status. Transoceanic telephone conversations are being carried daily by the Intelsat satellites, or, if the subject material is sufficiently interesting, TV programs can now be broadcast across the oceans.

Small User, Multiple Access Communications. In the system which was discussed previously, access to the communications satellites is only available to a relatively small number of large fixed ground installations. There is a great need for a second class of service which would permit small users such as individual aircraft, boats, or vehicles to communicate either with each other or with some large, central communication center. Limited tests have been conducted in this area, particularly with transoceanic aircraft flights[9-10], but as yet this service has not been put into regular use.

Military Communications Via Communications Satellites (An application of point-to-point communications). The military has already and will continue to use satellites for military communications. All of the tactical or strategic communications services that

* Superscripts denote references cited at the end of this chapter.

could be provided to the military fall within one of the previously mentioned classes. There are additional problems such as communications security and vulnerability. However, when military communications satellites are fully discussed later in this chapter with regard to national security, their relation to the previously discussed classes of communications satellite services is easily shown.

Broadcast

Voice Communications. Although there are still a variety of technical and operational decisions to be made, voice frequency broadcasts from communications satellites to individual users are feasible and the characteristics of such systems have been examined.[4,16] It is apparent that political considerations, as well as technological considerations, will strongly influence this type of service. From a political standpoint, the major difference from the two previous systems lies in the restriction of point-to-point communications to a small group of users whereas, with voice broadcasts, the general public can utilize the service. The educational and propaganda aspects of this service insure that political considerations will be involved. This is, of course, true for all other classes of service which reach the general public.

TV to Rebroadcast Centers. At the present time TV programs can be transmitted between two large earth stations at widely spaced points on the Earth. If the TV program received via satellite is to be rebroadcast from many conventional TV stations, it must be transmitted to the conventional TV stations by ground communications links, either by cable or microwave systems. However, an alternative type of communications satellite service has been studied in which the TV signals from the satellite would be broadcast to a number of ground receiving stations and rebroadcast from conventional ground TV transmitters which are relatively close to the satellite receiving station. In this class of service, satellite power would have to be increased and the ground stations would not have to be so technically sophisticated or expensive as the present ground stations required in point-to-point large user service. This type of service could be provided to large areas on the Earth which presently do not have TV broadcast service or have only TV broadcasts which originate locally.

TV to Modified Home Receivers. With this system, television programs are transmitted to the communications satellite from suitable ground stations and rebroadcast to modified home or small community receivers. This system would require antennas about 10 feet in diameter and a low-noise parametric amplifier at the ground receiver. The advantage of the system is that it can bring service to areas (in the U.S. or elsewhere) that are remote from a ground-based television transmitter. Several papers discuss various aspects of this system.[3,5,18]

TV to Unmodified Home Receivers. At present, the most ambitious program envisioned for communications satellites is the direct broadcast of television programs from satellite to an unmodified home receiver. The technological requirements for this system are much more severe than for the previously discussed systems. In part, this occurs because of the necessity for increasing the communications satellite's effective radiated power, since this determines the sophistication required in the ground receiving equipment. Increased output power implies increased satellite weight with the attendant increase in launch costs. Because of these factors, direct TV broadcast to unmodified home receivers may follow community broadcasts or broadcasts to modified home TV receivers by as much as 5 to 10 years. NASA is actively investigating the parameters of this system.[11]

Communications Satellite Objectives--Summary

Currently, the objectives of both the military and public communications satellite programs are to provide ever increasing services which will be developed on an evolutionary basis. The service which was first established, point-to-point communications between large users, reflects this evolutionary development. In this case technological shortcomings, in terms of equipment that could be mounted in the satellite and fine control of satellite antenna beams or patterns, were compensated for by providing sophisticated ground installations.[19] As the evolutionary process continues, the general trend will be for the communications satellites to become more sophisticated while ground terminals become less sophisticated. Expected future technological developments for the communications satellites include increased transmitter power, increased antenna gain, multiple antenna beams that can be directed toward any area within the field of view of the satellite, and increased flexibility of the satellite to operate in more than one mode.

Relation to National Goals

As will be demonstrated in this section, the objectives of the communications satellites programs can be directly related to the following national goals: National Security, International Affairs, Transportation and Commerce, Education and Knowledge, and General Government.

As would be expected, the degree to which various versions of communications satellites may help satisfy national goals and objectives varies. It depends in part upon (1) the priority assigned to the various national goals, (2) the extent to which each particular class of communications satellites can contribute to particular national goals, (3) political and social considerations, (4) satellite system cost estimates versus projected benefits, and (5) necessary technological innovation.

Before proceeding, it should be noted that quantitative estimates can be made of the costs and benefits of certain classes of communications satellites while in other cases estimates of both costs and benefits are partially qualitative. For example, in commercial practice the cost per channel mile of satellite communications systems can be compared directly to the cost per channel mile of submarine cables, microwave links, or other methods[16]; however, it may be impossible to provide firm or reliable estimates of the contribution made by communications satellites in international affairs on education of illiterate populations.

In the sections which follow, the contributions of communications satellites to particular national objectives will be discussed briefly. Where communications satellites have been used for some specific purpose, examples can be cited illustrating how communications satellites have contributed to a particular national goal. In the areas where a particular communications satellite service is futuristic, such as educational TV broadcasts directly to unmodified home receivers, the discussion can only be conjectural in nature. Wherever possible, references to mature discussions of a particular facet of communications satellites are provided. Lastly, this section contains the results of initial efforts to estimate the significance of the various communications satellite services based upon (1) their relation to national goals, and (2) the type of service which is provided.

National Security

The first military communications satellites, Initial Defense Communications Satellite Program (IDCSP), were launched on June 16, 1966.[12] Because previous studies had indicated the cost-effectiveness of launching a number of communications satellites at one time, this initial launch involved seven 100-pound satellites launched into an ~18,000 n. mi. near-synchronous equatorial orbit.[12,13] A velocity increment was added to each of the satellites to cause them to spread out and assume a random distribution. Since the initial launch, other launches through July, 1967, resulted in a total of 18 defense communications satellites. These satellites provide a limited operational capability between large fixed terminals. This is essentially a point-to-point large user system.[12]

The Initial Defense Satellite Communication System (IDSCS) was tested during the period June, 1966, to December, 1966. The successful results of the tests and the pressing need for long-haul military communications links led to establishment of an emergency operational capability between Hawaii and South Viet Nam and between the Philippines and South Viet Nam in December, 1966. The Pacific network was placed in an Initial Operational Capability status on July 13, 1967. As an indication of the contribution of these defense communications satellites to national security, there are several instances when failures in long-haul trunks of the Defense Communications System were restored by emergency use of the IDSCS.[13]

From May to August of 1967, a crisis developed in the Middle East, and IDSCS terminals in West Germany and Ethiopia were linked together as a primary communications trunk because of frequent outages in the more conventional HF radio trunks.[13]

During September, 1967, an emergency situation occurred in the Western Pacific Area when the commercial Transpac submarine cable broke east of the Philippines. During a period of 10 days, five of the highest priority military voice-frequency channels from the leased cable were rerouted from Hawaii to South Viet Nam via IDSCS.[13]

In October, 1967, a government-owned submarine cable from Thailand to South Viet Nam failed because of a break. Traffic between Hawaii and South Viet Nam, which was normally routed from South Viet Nam to Thailand via submarine cable and from Thailand to Hawaii by commercial satellites, was rerouted via the IDSCS link from Hawaii to South Viet Nam for a period of 10 days. The total rerouted capacity involved five voice-frequency channels.[13]

It is clear that the IDSCS already contributes significantly to national security. Future contributions can be expected to be even more significant. A major factor affecting future military communications requirements is the possibility of conflicts in remote areas and the increased mobility that our military forces will have in the near future. The C5A transport fleet will permit us to move large numbers of troops to any section of the Earth in just a few days. By using portable communications satellites ground stations, the military forces can establish an adequate number of communications channels within a few hours, instead of days as has sometimes been the case with previous communications links.

Long-haul communications are not the only services which can be provided by the IDSCS system or future military communications satellites. Backes[14] has covered the spectrum of available services by pointing out four types of needs which can be met by communications satellites:

(1) Global coverage, large user -- point-to-point communications links between large communications centers

(2) Global coverage, small user -- point-to-point communications between small units such as ships, airplanes, or vehicles

(3) Regional coverage, small user--point-to-point communications between military units in some small, specific area of the Earth, such as South Viet Nam

(4) Regional coverage, large user--point-to-point communications between large military organizations and units in a small geographic area.

Although the referenced article covers the needs in detail, a brief discussion of items (3) and (4) above will point out the urgency of the needs and how communications satellites can meet these needs. Concerning item (3), the conflict in South Viet Nam has shown that there are serious problems in communications between small ground forces. Communications range with typical man-pack equipment is quite limited. In a number of cases additional forces must be used to relay messages from patrols to a headquarters unit. The seriousness of the problem is further accentuated when the large number of programs bearing on communications in the South East Asia area is considered. For example, ARPA/AGILE has sponsored several millions of dollars worth of basic propagation and radio noise studies in an attempt to improve tactical communications.[21,22] Narrow beam satellites offer a partial solution to this problem. Backes[14] points out that a 5 megabit per second data or information transfer rate could be achieved with a 1 foot diameter antenna on Earth, if the satellite antenna beamwidth is of the order of 1 degree. Further, only 3 watts of satellite transmitter power would be required. A 1 degree beamwidth antenna in the satellite would provide coverage over a roughly circular area with a diameter slightly greater than 400 miles. A satellite having multiple narrow beams could provide direct communications between small field units and major command centers thousands of miles from the direct scene of the action. As a corollary, more direct control of small units from major headquarters can be achieved. One can readily visualize that, in the future, an officer located in CONUS could directly control small field units.

Concerning item (4) Backes[14] has also noted that the major current communications links (tropospheric scatter) between Thailand and South Viet Nam could be replaced by a communications satellite system that employed three ground stations in South Viet Nam and three in Thailand. One or more of the terminals in this case could be used to handle out-of-theater traffic. For operation in the Southeast Asia area, comparative analysis indicates that communications satellites could provide service for an average cost of $42,000 per circuit for a 600-circuit system versus $200,000 per circuit for an average 400 channel-mile linkage employing more conventional communications links. In this sphere of operations, 150 channels appeared to be the crossover point.[14]

There are many other aspects of military communications circuits, such as channel security, reliability, and flexibility, that must be considered. However, the few examples cited and others in the literature leave no doubt that communications satellites are now and will continue to contribute in full measure to national security goals in a unique and highly effective manner.

As an example of the impact of communications satellites on military planning, the Air Force is now considering an integrated system involving communications satellites in which one channel could provide communications, navigation, and identification for an aircraft.[6] Costs for this program could run into billions, but proponents of the system consider it to be worthwhile. Before the introduction of communications satellites such a system could not have been possible. Other communications satellite systems to serve the Air Force have also been discussed in the literature.[7,8]

International Relations

Viewed purely from the standpoint of the proportion of gross national product that the United States has donated or loaned to other nations for philanthropic uses, the United States is unique in terms of the intensity and duration of its efforts to provide aid and assistance to upgrade the living standards of other nations. Thus, one of our goals in international relations can be stated as "making the world a better place in which to live". It is true that we seek in some measure to serve our own national interests through this assistance, but it is also true that in some measure we are unselfish in this assistance.

Our effectiveness in improving world living conditions depends to a large extent upon how we are viewed by the peoples of other nations. Thus, a complementary goal of the U.S. is to persuade the rest of the world to look upon the U.S. with friendly eyes. In addition, it is certainly a national goal to insure a peaceful world so that expenditures for military purposes can be diverted to the improvement of world living conditions.

The questions to be examined here are "How can communications satellites contribute to this (or these) national goal(s)?" and "How cost-effective are these contributions when compared with other alternatives?" There appears to be little doubt that communications satellites contribute to the prestige of the United States. However, measurements of this contribution (for example, as with world-wide TV broadcasts of the Olympic games) is now largely subjective, although world-wide opinion sampling might produce more definitive measurements.

To date, international TV broadcasts have occurred only as short-time special events and as a result have only short-lived effects. However, as TV service is extended to remote areas of the earth for longer periods of time the general effect will be cumulative and the world's opinion may well be influenced by programs designed to provide information on matters of international interest. The voice broadcast service also contributes in this respect. One factor that is not immediately apparent with satellite broadcast services is the difficulty of effectively jamming a global satellite broadcast service, particularly where UHF or higher line-of-sight frequencies are used. Thus the U.S. may, under certain circumstances, be able to provide information to areas where normal radio services are temporarily jammed. This capability can be of assistance in meeting our international goals.

The nations of the world have cooperated for many years in the control and utilization of the radio frequency spectrum. This spirit of cooperation is continued in the COMSAT program which gives each of the member nations a voice in the program. The importance of international communications regulation and cooperation generally appears to have been recognized rather quickly. For example, Marconi received his first patent on wireless telegraphy in 1896, and the first International radio-telegraph conference was held in Berlin in 1903.[23] Since then, international bodies have worked together in regulating radio communications. It is fairly clear that the communications satellite programs intensify the need for international cooperation because such cooperation is imperative to their proper use and regulation. In fact, experience with Intelsat has underscored both the advantages and problems arising from international participation and control in communications. The fact that nations cooperate in this important area on a regular basis should contribute to mutual understanding between the nations.

Communications satellites can provide, on relatively short notice, high density communications services to any area of the world in the event of disaster. This is especially valuable for those areas of the world which are "communications poor". Thus, the need for the capability of providing such emergency communications services in the mountainous areas of South America or sparsely settled regions of Iran or Turkey are greater than it is for Switzerland, which has adequate communications facilities for almost any emergency. The ability of the U.S.-developed communications satellites to provide these services during emergencies can only enhance our stature in international affairs.

In the past, there have been many instances of difficulty in negotiating conference sites suitable to all parties in some international dispute. There are many psychological and political factors involved in such discussions; however, the speed with which temporary, but satisfactory, communications facilities could be provided to any part of the world provide a highly desirable additional flexibility in international affairs.

Evidence of the continuing growth in importance of international communications to the U.S. is provided by projections that the U.S. will require 5,770 international voice circuits in 1975 (nearly 40% for government), compared with 1,035 in 1965 (about 13% for government).[26] The unique characteristics of communications satellites make them extremely attractive in establishing and maintaining the facilities required (under these projections) with sufficient speed and flexibility to satisfy the fluid international environment which can be visualized for the time period to 1975.

Commerce, Transportation, and Communications

Commerce, transportation, and communications might well be termed the life blood of a nation. Anything which contributes to the efficiency in the flow of materials, people, and information is beneficial since it aids the U.S. and other nations of the world in achieving national goals. Quotations from authoritative sources indicate[27] that international telephone costs have been reduced by 15% in the evolutionary rate negotiation process in the short time since communications satellites were introduced. This rate reduction is positive evidence of communications satellites contributions.

In moving material and/or people from point to point, any facility which increases transportation speed, or lowers investment and operating costs are beneficial. Future small user point-to-point communications services made possible by communications satellites can provide unique services which could contribute significantly to improvement of transportation. For example, ships, which now cannot leave a port until all manifests have been checked and corrected, could be dispatched immediately upon being loaded. Manifests could be checked and corrected while the ship is underway if continuous facsimile communications services could be supplied between ship and shore. This appears to be impractical with present radio channels because of the high utilization rate for this portion of the frequency spectrum. Additional communications capacities offered by commercial communications satellites could make such operation feasible. This same service should also be valuable in solving similar problems for the heavy projected future international air freight traffic. For personal international travel, passports could be relayed by facsimile, thus speeding entry into a country.

Presently, the major internal U.S. freight carriers are trucks and trains; however, in the near future, it is anticipated that an increasing amount of freight will be moved by air. Communications between ground terminals for the truck and train segments of the transportation system are certainly adequate with present communication facilities. However, there are instances in which improved capabilities to contact road mobile units enroute could reduce or avert costly delays of breakdowns, traffic congestion and similar situations. Although satellite communications may be able to provide benefits for ground links, it may contribute more to the control of air traffic as current congestion conditions become worse.

In the area of general commerce, communications satellites can provide unique services in some instances and augment available services in others. For example, when coupled with other applications satellites to search out and track schools of fish, control and productivity of fishing fleets can be enhanced.

At the present time, aircraft are spaced at wide intervals during transoceanic flights. This spacing is necessary because precise location of the aircraft is not known, and the aircraft can not be contacted reliably during all portions of the flight. Better location techniques and communications, both of which are practical to communications satellite applications, can lead to denser transoceanic flights. This will have a direct bearing on the operations and profits of both passenger and freight flights.

Perhaps the most pressing problem in this area is communications with aircraft during transoceanic travel. High frequency (3 to 30 MHz, at this time the prime frequency band for links between planes and traffic control centers) can be influenced by ionospheric disturbances producing static or complete communications blackout. In addition, the high frequency spectrum is crowded. VHF communications (30 to 300 MHz) is high quality as far as fade-free performance and static are concerned. However, the effectiveness of this frequency band for transoceanic use is limited by the line-of-sight coverage between communicating stations. With anticipated increase in aircraft density, the severe limitations on the spacing of aircraft arising from various communications problems lend a sense of urgency in seeking solutions.

Several experiments have demonstrated that satellites can provide VHF communications links between ground stations and aircraft, and between aircraft. These experiments have been evolutionary in nature as have the other communication satellite programs. One-way communication from the NASA station at Camp Roberts in California to a Pan American World Airways 707 was accomplished on November 22, 1964. Teletype signals at rates varying from 50 to 60 words per minute were transmitted via SYNCOM III. The messages were received and copied aboard the aircraft with an error rate of less than one bit per thousand.[9,10]

Two-way transmission was achieved by the same aircraft on January 26, 1965. In this case the aircraft had two 200-watt transmitters and teletype signals were transmitted two ways between the NASA station at Camp Roberts and the aircraft on its way to Honolulu. On December 10, 1966, Pan American, American Airlines, TWA, and United participated in a two-way voice communication experiment using the first Applications Technology Satellite (ATS-1). Test results were good although multipath effects did cause 6 to 12 db signal fading for some 5 to 11 seconds. The fading occurred at the fringe of the satellite's area of coverage. Japan Air-Lines, Quantas (Australia) and Avianca (Columbia) have also participated in similar communication experiments, and the results have been good. Additional aircraft-ground VHF communication experiments and tests are planned with ATS-III with a number of European airlines, the FAA and ARINC participating. Plans to provide services on a regular operational basis are underway. Future plans include tests to be performed in the UHF (300 to 3000 MHz) band to determine the effectiveness of this band and for air-ground communications via satellite. It appears that the first opportunity to investigate UHF capabilities may be delayed until 1972, on the basis of the projected availability of spacecraft.

Besides offering a much needed capability for simple ground-air communication, various ranging techniques can be used to establish the position of aircraft. Although it is expected that future aircraft will be equipped with inertial navigation systems, an independent check of aircraft position is desirable. The increased accuracy and reliability of position data should permit reduction of spacing of transoceanic flights, thus alleviating a situation which is already serious and could become more serious in the near future.

This application is sufficiently important that ARINC, representing all domestic air carriers, is now negotiating with Comsat for a Pacific and an Atlantic communications satellite to be used for transoceanic aircraft communications.[28] These satellites will use Pan American's ARINC approved Digicom system which will automatically report aircraft identity, position (from an onboard navigation system), flight route, altitude, time of reporting, airline bookkeeping information, and analyses of engine operation. Navigation satellites to provide an independent report of aircraft position are also being considered by ARINC.

One recent entry affecting communications requirements involves the need for transferring large volumes of data and for linking computers separated by significant distances. There have been many predictions by computer and communications experts concerning the rapidly increasing importance of this capability in commercial and other activities. The flexibility and cost-effectiveness of satellite communications makes it attractive for international activities of this nature. The importance of this area and the problems arising between data users (usually computer oriented companies) and transmitters (i.e., communications industry) has been discussed in a recent paper by Irwin.[29]

There is little basis for estimating the total impact of satellite communications on the world, or even U.S., economy. However, operations surrounding Intelsat do involve substantial sums of money and many organizations. For 1 hour of color TV transmission between New York and Paris, service charges vary from $11,500 to $18,625--depending on time of transmission. For black and white TV, charges vary from $8,350 to $13,100. Four U.S. companies (i.e., ITT, AT&T, Western Union International, and RCA) buy Intelsat's time and sell or lease to clients in 62 countries. Return on investments for such operations have been high. From a total investment of $103 million through July 31, 1968, members of the consortium have distributed $33 million in profits. Comsat, representing the U.S., realized a net income of $3.3 million during the first half of 1968.[30]

Education and Knowledge

Probably the strongest argument for uses of communications satellites in education derives from their potential in providing educational programs to those areas which do not have adequate educational facilities, or where masses of educational material is not readily available. Haviland[5] discusses in detail the use of communications satellites in providing television services to points that ordinarily do not have a TV station available. Thus, for example, even in the United States, Haviland notes, it took approximately 10 years to achieve 95% coverage of the U.S. by at least one TV signal, and that 100% coverage had still not been achieved in 1968. For the underdeveloped countries, communications satellites can provide educational programs to areas that it would not be economically feasible to reach by other communications techniques.

Some of the services that can be provided by communication satellites for education purposes are covered in a paper by Jamison.[16] He divides the instructional systems involving satellite communications into four alternative classes. These are radio, television, programmed radio, and computer-assisted instruction. Radio, in the sense that Jamison is using the term, is simply a series of programs with educational content that could be broadcast directly into the home. These might include cultural material as well as formal courses. Television classes would employ the same type of material as audio instruction, augmented by visual aids appropriate to the medium. With programmed radio, Jamison visualizes using 600 voice channels and programming the system so the student could select a particular lecture in a continuing series by setting his radio to the proper frequency. The various lectures would be programmed so the pupil could select serial lectures as fast as he could absorb them, or he could skip 2 or 3 days of study and still be able to pick up the next lecture in the series.

Jamison visualizes these first three systems as being applicable to relatively underdeveloped areas. Computer-assisted instruction, on the other hand, would require fairly sophisticated ground equipment and could bring any advantages associated with computer-aided education to a broad audience. The capital investment required for the latter system would probably restrict its use to the more highly developed countries.

Compared with the rest of the world, the U.S. already enjoys a high level of general education, so that additional benefits to be derived from an educational system employing satellite communications require careful examination before implementation. For the many underdeveloped portions of the world, however, the immediate benefits to be obtained would be of extreme importance to the general welfare of the country. Thus, in assessing the contribution of education via satellite, the benefits--to the U.S.--of world-wide education must be considered.

Jamison has, for example, compared the costs and benefits of educational systems in Northern Nigeria with and without satellites.[16] This linear programming study indicated that substantial benefits could be derived by using satellites. In this case, Jamison notes, the satellite-supported system did not reduce the costs of the educational system but did succeed in breaking a bottleneck resulting from a critical teacher shortage. This, in turn, permitted a greater number of students to be educated and, in this manner, increased the benefits of the satellite education systems (for equal dollar investment) over the education systems without satellites.

Costs of the educational satellite systems must, of course, be considered when assessing benefits. Rosen[3] has examined the problem and reports that 10 million people could be reached for an annual cost of about $1.00 per person in both well developed and underdeveloped areas. For remote areas, 10-foot antennas would be required and the required electrical power could be supplied by manpower, if necessary.

Even for a highly developed nation like the U.S., the possible benefits of additional educational facilities must be carefully considered. Various publications have noted repetitively that the unemployed in this country are not unemployed because of a lack of jobs but, rather, because they do not have the education required for the available jobs. Welfare expenditures in the U.S. run into billions of dollars and, if only a fraction of this expense could be saved by additional education facilities, the facilities would pay for themselves. How, or whether, communications satellites can be used effectively for this purpose is not clear at this time.

As an example of how fast things are moving in the education area, NASA has an informal agreement with India to use an ATS-F satellite as a TV relay in the 1971 time period.[28] This experimental program is designed to bring TV broadcasts from New Delhi to over 1,000,000 square miles of the Indian Subcontinent. The programs will be directed towards birth control and better methods of farming. These are both critical problems for India and the effects of this experiment will be extensive. India now has less than 1000 TV sets but the government hopes to provide 30,000 sets in 5000 localities by 1971 so that large numbers of the population can be reached.

General Government

General government can be considered the overall functioning of the various units of government (local, state, and national). Some of the generally accepted ways that the additional facilities provided by communications satellites can contribute to the efficient functioning of general government include the following:

- Communications channels can be added relatively easily to existing systems to transmit the increasing volume of point-to-point messages.
- Communications services can be provided to areas which are temporarily in need of better communications facilities.
- Communications channels provided by the sattellites can be utilized for priority or emergency messages when other channels have temporarily broken down. This has been previously discussed in the section on National Security in which several examples are given of messages being routed via communications satellites because transoceanic cables had failed.
- Communications between mobile units of various government bodies, such as law enforcement agencies, could possibly increase the efficiency of their operations.

With the existing sophisticated communications system in the U.S., the current need for additional services for the ordinary conduct of governmental business is not critical. Where communications satellites can provide alternate communications channels in the case of energencies, they are of benefit to the particular branch of the government that must maintain communications.

With respect to the last item above, for example, the status of internal security of the nation can be related to the crime rate and the effectiveness of the forces of law and order in maintaining the individual security of each of its citizens. The potential value of point-to-point, small user, multiple access communications channels which can be established by communications satellites for use between mobile units has been discussed previously. The ability of law enforcement agencies to maintain communications at all times can materially contribute to the effectiveness of this facet of general government.

Evaluation of Communications Satellite Goals to National Goals

Table VII-3 represents an evaluation of the significance of each of the six communications satellite goals or services to national goals. The criteria for this evaluation are listed at the bottom of the table. No formal evaluation process has been used since this would represent a major study in itself. Thus, this evaluation is subjective and represents only the views of the author as influenced by the papers and reports of others. Large user, point-to-point, (fixed) service is critically significant to National Security. Small user, point-to-point, multiple access (mobile) service is also critically significant in National Security activities. Thus, both of these items receive a 5 rating. Voice broadcast to small users may well be useful for warning the public in emergencies and the various TV broadcast services would also be useful although they are clearly not necessary. For this reason voice broadcast and TV broadcast receive a rating of 1 under National Defense.

Similarly, under international affairs both classes of point-to-point services have objectives that are in support of National Goals and are assigned a rating of 4. Broadcast services can contribute and are assigned a rating of 3, except for the TV broadcast services to unmodified receivers. This class of service, properly utilized, could assist the U.S. in obtaining support from the general public in far corners of the Earth and thus is directly in support of National Goals and receives a rating of 4.

In commerce, transportation and communications small user, point-to-point multiple access (mobile) service is critically significant, particularly in oceanic airplane traffic control and receives a rating of 5. Large user, point-to-point service is deemed less critical and receives a rating of 3. The constant fundamental relevancy was assigned for space, due to past and potential future contributions to satisfying Space and Communication Satellite Act goals and because of probable future utility in relaying messages from Earth-orbiting space stations and from deep space probes. Other ratings in the matrix were established similarly.

Technology Considerations and Trends

Table VII-4 lists estimates of weights, power requirements, and antenna beam characteristics of in-service and anticipated communications satellites for the various services of interest here. Forecasts of technological needs and objective completion dates for each class of service are also listed in the table. It is clear that higher powered and more efficient broadband amplifiers will be needed to provide the evolutionary capabilities that have been envisioned. Also, because of the limited area available for synchronous satellites, narrower beam and controlled beam antennas will be required.

The objective of these developments is increased capacity. Morrow has pointed out that increased system capacity for a given investment in space and surface equipment can be achieved most effectively by maximizing satellite transmitting power and antenna gain per unit satellite mass.[42] To achieve these objectives Morrow separates the components of a typical communications satellites into the following:

(1) DC power plants
(2) Communications transmitter
(3) Communications equipment
(4) Antenna systems
(5) Stabilization and station-keeping systems.

Improvements in all of these areas are required to achieve some of the communications satellites objectives that have been discussed in this paper. However, from the viewpoint of various sources, the technological advances required are evolutionary in nature and will certainly be achieved. One can postulate communications systems that depend upon technological advances and even develop a time table to show when the required technological advances will become available. Thus, 10 years for a 10 kw power

TABLE VII-3. ESTIMATE OF RELEVANCY OF COMMUNICATIONS SATELLITES OBJECTIVES TO NATIONAL GOALS

System or Service	National Security	International Relations	Commerce, Transportation and Communications	Education and Knowledge	General Government	Space
Large User, point-to-point (fixed)	5	4	3	1	4	4
Small User, point-to-point, multiple access (mobile)	5	4	5	1	5	4
Broadcast - Voice to small user	1	3	1	3	3	4
Broadcast - TV to broadcast center	1	3	1	3	3	4
Broadcast - TV to modified receiver	1	3	1	3	3	4
Broadcast - TV to unmodified receiver	1	4	2	3	3	4

5 Critically relevant
4 Fundamentally relevant
3 Advantageously relevant
2 Conveniently relevant
1 Remotely relevant
0 No apparent relevancy

TABLE VII-4. SATELLITE PARAMETERS VERSUS CLASSES OF SERVICE

Class of Service	Satellite Weight, Pounds	Satellite Total Input Power	Satellite Total Transmitter Power	Antenna Coverage: Maximum Coverage	Antenna Coverage: Intermediate Coverage	Antenna Coverage: Narrow Beam Steerable	Reference	Technical Consideration and Forecast
				Point to Point				
Large user, fixed								
240-2 way telephone circuits	85 (Intelsat 1)	33 W	20 W (EIRP)		Tilted + 7° to cover northern hemisphere 11° x 350°		32	Now (a)
240-2 way telephone circuits	190 (Intelsat II)	75 W	35 W (EIRP)	Beam centered on equator 12° x 360°			32	Now (a)
1200-2 way telephone circuits	270 (Intelsat III)	125 W	300 W (EIRP)	Beam centered on equator 20° x 20°			32	1969 (a)
3600-8000, 2 way telephone circuits	1200 (Intelsat IV)	500-600 W	2400 W (all power in 20° beam incl. batteries	1 each, 20° x 20°		2 each 4.5° x 4.5°	32	1970 (a)
Small user, multiple access								
VHF, and UHF systems being considered	400-600	400-800 W	200-400 W		Cover Atlantic air traffic		7, 10	1972-1975 (b)
				Broadcast				
Voice to small user								
Shortwave (4356 nm, 4.8 hr, circular orbit	4873	7 kw	15.4 kw (during broadcast, using batteries partially)				4	1973 (b)
FM service to U.S. -- Geostationary orbit	2469	11.38 kw			U.S. coverage		4	1973 (b)
FM service to specified areas of earth--7556 nm, 8 hr, circular orbit	835	1.36 kw				Narrow beam (remote controlled, steerable)	4	1973 (b)

(a) State of the art is adequate.
(b) State of the art needs improvement.
(c) Technical breakthrough required.

TABLE VII-4. SATELLITE PARAMETERS VERSUS CLASSES OF SERVICE (Continued)

Class of Service	Satellite Weight, Pounds	Satellite Total Input Power	Satellite Total Transmitter Power	Antenna Coverage: Maximum Coverage	Antenna Coverage: Intermediate Coverage	Antenna Coverage: Narrow Beam Steerable	Reference	Technical Consideration and Forecast
			Broadcast (Continued)					
TV to modified ground receivers								
New antenna, pre-amp & FM/AM converted. Suitable for a community, a building in town, or remote village Too expensive for individual user	1100	2kw	2-200 W repeaters			4° beam directed toward zone to be served	18	1979 (b)
TV to rebroadcast centers								
Geostationary orbit	375	140 W	10 W transmitter power E.R I.P. depends upon antenna beamwidth	18° (for use with large ground antennas and telephone comm. global coverage)	10° (to cover the West Indies and Guina)	4.50 (to cover Africa)	18	Now (a)
TV to unmodified ground receivers	20,000-70,000	10-35 kw	5-15 kw		Continental U.S. or similar area		11	1985 (c)

(a) State-of-the-art is adequate.
(b) State-of-the-art needs improvement
(c) Technical breakthrough required.

amplifier capable of broadcasting TV signals to small stations on Earth might be a reasonable schedule. However, the solution of nontechnical problems may take a considerably longer period of time. This is discussed further in the section on "Political and Sociological Considerations" in this chapter.

A major source of concern, in terms of political considerations, is the limited space available for stationary communications satellites. Bradley has examined the problem of the maximum number of communications satellites in geostationary orbits.[24] He asserts that, to achieve optimum capacity with a given size ground antenna, satellite transmitter power should be large so that capacity is limited only by mutual interference and not by electrical noise. Using this and other assumptions, it is then shown that, for a communications system with 20-foot diameter Earth-based antennas, 2.1 satellites per degree of orbit would be a reasonable solution. This particular spacing was based on satellites which would cover all of Earth visible from the satellite and is not true for satellites which would cover a more limited area. Bradley clearly points out, as have other authors[25,35] that the amount of space available for geostationary communications satellites is indeed limited. Further, the maximum number of satellites for any given system arrangement depends upon mutual cooperation between all parties that put communications satellites into synchronous orbit. If mutual cooperation is not in effect, then the number of useful satellites that can be put into orbit would be seriously reduced. Therefore, to make optimum use of communications satellites, international cooperation is a must or all parties will suffer.

Political and Social Considerations

Although there are technological limitations to communications satellites at the present time, it is almost certain that the required technological innovations can be achieved. However, political and social considerations may form an effective deterrent to maximum utilization of communications satellites. Several authors have suggested that the primary problems with satellite communications are organizational, managerial, and procedural rather than technical or economic.[20,25,31,35,36]

Fortunately, there has been a long history of international cooperation in the area of communications. As early as 1903, for example, an international congress met in Berlin to establish rules which would prevent shore radio installations from refusing messages from ships at sea. (A summary history of international cooperation in the area of radio communications can be found in a report by the Institute of Electrical and Electronics Engineers and the Electronic Industries Association.[23] It reflects a long, and successful period of international cooperation in this area of common interest.)

The political world readily estimated the effect that communications satellites would have and, from the fall of 1963 until summer of 1964, a number of nations discussed the type of organization needed to regulate communications from satellites. As a result of these discussions, the International Telecommunications Satellite Consortium (Intelsat) was organized on August 20, 1964. About a dozen countries signed the original agreement, and there are now more than 60 countries participating. The importance of this new communications technology, as viewed by the member nations, is apparent from the preamble of the agreement. Article I(a) of the preamble reads as follows.

> The Governments signatory to this Agreement, Recalling the Principle set forth in Resolution No. 1721 (XVI) of the General Assembly of the United Nations that communications by means of satellites should be available to the nations of the world as soon as practicable on a global and nondiscriminatory basis;
>
> Desiring to establish a single global commercial communications satellite system as part of an improved global communications network which will provide expanded telecommunications services to all areas of the world and which will contribute to world peace and understanding;

Determined to this end, to provide, through the most advanced technology available, for the benefit of all nations of the world, the most efficient and economical service possible consistent with the best and most equitable use of the radio spectrum;

Believing that satellite communications should be organized in such a way as to permit all States to have access to the global system and those States so wishing to invest in the system with consequent participation in the design, development, construction (including the provision of equipment), establishment, maintenance, operation and ownership of the system;

Believing that it is desirable to conclude interim arrangements providing for establishment of a single global commercial communications satellite system at the earliest practicable date, pending the working out of definitive arrangements for the organization of such a system;

Agree as follows:....

This document expresses the interest of the signatory nations in applying the benefits of communications satellites to all. However, Pardoe and Steines[1] have pointed out some of the conflicting interests that have already arisen and must be settled by agreement to prevent communications interference between communications satellites systems conceived and implemented by various political entities. The Western European nations have, for example, established in 1963 a forum for interested parties to discuss space applications including communications satellites; France and Germany entered into an agreement in June, 1967, concerning an experimental communications satellite program; the Soviet Union established the world's first regional communications satellite, Molyna I, in 1965 to distribute TV programs to some 20 ground stations in the USSR. Further, it is planned to extend this system of satellites to other regions. Canada is considering its own communications satellite and has applied formally for a reserved location in equatorial synchronous orbit. Japan is considering a system to link her various island communities. Unless agreements on operating frequencies, power levels, coverage, and type of service can be reached on an international basis, the full benefits of communications satellites to the world in general can not be obtained.

The International Telecommunication Union (ITU) has made a strong plea (The Secretary General of ITU, Mr. Mohamed Mili, in his opening address to the World Plan Committee meeting in Mexico City in October, 1967) that ITU be given authority to administer all satellite communications systems. Whether ITU should be the regulating body may be open to question, but the desirability of a single regulating body is increasingly apparent.

Pardoe and Steines[1] point out some of the shortcomings of Intelsat, as seen by Europeans and by COMSAT, as an organization for fulfilling its objectives while the American author, Metzger[32], speaks of Intelsat in laudatory terms. The problems are complex and the time remaining to structure definitively all aspects of communications satellites (service to be provided, sharing of costs and income, and distribution of the equatorial synchronous orbit) is becoming brief when compared to the length of time that may be required to reach agreements that are satisfactory to the parties involved.

This problem of reaching agreements on the applications of space, including communications satellites, is pointed out in two recent articles[33,34] reporting on the first United Nations Conference on the Exploration and Peaceful Uses of Outer Space. Some of the more significant facts or comments reported in these articles include:

- The U.S.S.R. proposed an INTERSPUTNIK Worldwide satellite system in which each nation participating would have one vote instead of a weighted vote as in the INTELSAT Consortium. No details were presented on the proposal.

- The meeting was attended by more than 500 delegates from 80 nations with diplomats and government officials rather than engineers and scientist (including NASA Director James Webb, two U.S. congressmen, A. A. Blagonrovov of the U.S.S.R. and Cosmonaut Alexei Teonov of the U.S.S.R.).

- The problems of the developing countries as far as space applications are concerned were pointed out in a paper presented by Sierra Leone.

- Problems connected with satellite education and legal problems were discussed.

- Arthur C. Clarke, internationally known scientist and earliest advocate of communications satellites commented on the Soviet Troops entering Czechoslovakia, "You know, 20 years from now this could never happen, because with a treaty global satellite system, you couldn't jam radio broadcasts and hide the true news about what's happening from the people".

- The developing nations were primarily interested in Space Applications not space science.

Costs

The costs of a communications satellite system are contained in the following:

- The cost of the satellite (considering the probability of a successful launch and satellite operation)

- The cost to launch the satellite into orbit (considering the probability of a successful launch)

- The cost of construction and operation of the ground stations.

Costs vary with the functional service to be provided by systems. Evans, for example, estimates the total cost of a synchronous relay satellite, including boosters, at about $15 million total per satellite.[37] This satellite is to be used with a point-to-point, large user communications link, and the cost of the sophisticated ground station is high. Evans has estimated the cost of a high quality ground terminal as $3.5 million per station with a 25-foot antenna to about $5 million with an 80-foot antenna. The satellite considered is sophisticated in that it is capable of handling both telephone and television transmissions with a capacity of 10,800 two-way telephone channels. Powers[38], on the other hand, reports the total cost of a synchronous relay satellite as about $5 million including the launch cost. Although it is not clear, he is evidently referring to satellites of the Intelsat I or II class.

Various other references[3-5,17,32,39] also deal with the cost of various classes of satellite communications services. For example, Swensen[17] discusses the costs of TV rebroadcast systems (i.e., the satellite broadcasts to widely separated ground stations which then rebroadcast via local ground transmitters). Typical costs for ten TV channels to broadcast from the satellite to 225 ground stations is estimated at about $40 million or about $4 million per TV channel. For 42 TV channels the cost per channel drops to about $1.4 million per channel.

As communications satellites provide additional services their weight and power requirements grow. Intelsat I, for example, weighs 85 pounds and uses 33 watts of dc power; Intelsat II weighs 190 pounds and uses 75 watts of power; Intelsat III weighs 270 pounds and uses 125 watts of power.[32] All of these satellites providing TV service to service between large users. For communications satellite providing TV service to unmodified home receivers, power requirements have been estimated at 10 to 15 kw of input power.[11] This would bring the weight of this particular satellite to 20,000 to 70,000 pounds based on 2 pounds per watt. This latter figure probably represents an upper limit on communications satellite weight. Indeed, these high figures should be conservative since several programs are directed at reducing weight and increasing the capabilities of communications satellites.

Fortunately, the cost per pound of payload in synchronous orbit has a definite downward trend. Metzger reports the cost of Intelsat I as about $40,000 per pound; Intelsat II about $20,000 per pound; Intelsat III as about $14,000 per pound.[32] There is some question as to these costs as the payload approaches 2,000 pounds. McGolrick and Davis[41], and Johnson and Davis[44] point out that approximately 39,600 feet per second launch velocities are required to establish a synchronous orbit. Figure 8 of Reference 41, indicates that Titan IIIC is capable of delivering about 2000 pound payload to this orbit. However, for larger payloads, only Saturn V is now available. This would not be economical unless single large or multiple satellite payloads of about 60,000 pounds were required.

It may be desirable to postulate a launch vehicle with greater capabilities than Titan IIIC but less than Saturn V. Various launch vehicle configurations are being considered for this purpose. Decisions on satellite and launch vehicle configurations are relatively independent. The Delta launch vehicle, since the beginning of the Delta program, has increased its payload into the synchronous transfer orbit from about 100 pounds to 785 pounds.[41] This has reduced the cost per pound of payload in synchronous transfer orbit from $25,000 to $5,100 even though the cost of a Delta launch has increased from about $2.5 million to $4.0 million.

Despite the high cost figures quoted here, it should be noted that the commercial satellite services have been shown to be practical from a cost standpoint. This accounts for the plans that are being made by numerous countries or groups of countries to provide such services to their citizens.

Considerable experience has now been gained with the present generation of satellites, surface systems, and launch vehicles to permit accurate prediction of the cost of putting satellites into service. As has been stated previously, satellites have been demonstrated to be competitive on a cost basis with other systems providing similar benefits. Thus, it is clear that point-to-point services between large users are cost-effective. Based on experiments conducted for communications via satellite for trans-oceanic flights, it appears that this service can also be competitive on an economic basis and, in addition, the service that can be provided in this case appears to be unique to communications satellites. Whether other services can be equally as competitive on a cost basis is still a matter of conjecture in some cases. At present, the most controversial question appears to involve educational services via communications satellites.

NASA Role

The National Aeronautics and Space Administration was created to insure that the United States would occupy a leading position in space. NASA's role in communications satellites has been recognized as extremely important both in legislation and as a basic principle permeating the entire NASA structure. NASA's efforts have been directed along two principal lines of effort:

(1) Improving basic communication technology
(2) Providing appropriate launch system capabilities at low cost.

Basic Communication Technology Considerations

NASA is required, by act of Congress, to assist COMSAT in fulfilling its objectives. As has been stated previously, the communications satellite program has been evolutionary in nature. From the standpoint of the burden on the communications satellite, the first services that were inaugurated, namely point-to-point communications between large users, took full advantage of the capabilities of ground-based stations. As more extensive services are provided, the satellites will be more sophisticated in nature, and more technological advances will be required. NASA has and can continue to fulfill its commitments in satisfying these technology needs by the following means:

- Definition and design of interference experiments. This is a fundamental problem, since it can be shown that, eventually, communications satellites will be limited by interference rather than transmitter power, steerable antenna capabilities, or other technological factors.[24]

- Investigation of the frequency spectrum of VHF and frequencies above 10 GHz. Certain classes of services, such as voice broadcast or point-to-point service between small mobile users, requires investigation of VHF while the utilization of frequencies above 10 GHz can minimize interference with Earth-based services which use the microwave spectrum.

- Orbital spacing investigations. It is clear that, given a certain class of service, only a given number of synchronous satellites can be employed without mutual interference.[24]

- Support of U.S. positions on international telecommunications matters. As has been noted previously, the future benefits and importance of communications satellites has been recognized worldwide. There is a tremendous undercurrent of conflicting interests.

- Participation in the International Radio Consultative Committee (CCIR). NASA participates in Study Group IV, Space Systems, which covers satellites and other systems for communications and inputs are technical and performance characteristics, feasibility of frequency sharing, and technology forecasts. CCIR is the technical subsection of ITU, the international regulating body for radio communication and is responsible for questions on broadcasting, the reporting on various technological factors, and the recommending of courses of action.

- Basic studies designed to provide technological support to Small User, Multiple Access Communications satellites. This includes theoretical studies of modulation techniques; Time Division Multiplex (TDM) experiments with Relay II and with ATS-1 (Japan); single sideband (SSB) phase modulation experiment with ATS-L; demand assignment multiple-access techniques; and multiple-beam antenna development.

- Basic studies designed to provide technological support to space broadcasting activities. This includes voice broadcast satellite mission studies; TV broadcast satellite mission studies, and technology investigations (such as on high power, high efficiency, broad band transmitters). In addition, NASA has supported the joint NASA/INCOSPAR study group on the ITV experiment and provides technical consultation and assistance to a variety of U.S. bodies including the President's task force on communications, HEW, FCC, STATE, USIA, OTN Corporation for public broadcasting, and to the Congress of the United States.

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CHAPTER VIII. EARTH RESOURCES SATELLITES

GOAL: To contribute to the understanding and management of Earth resources of economic, social, and cultural interest

RELATION OF EARTH RESOURCES SATELLITES TO NATIONAL GOALS:

PROGRAM OBJECTIVE AREAS	NATIONAL (FUNCTIONAL) GOALS: EDUCATION & KNOWLEDGE	SPACE	NATIONAL SECURITY	VETERANS	LABOR & MANPOWER	WELFARE	HEALTH	COMMERCE, TRANSPORTATION, & COMMUNICATIONS	GENERAL GOVERNMENT	AGRICULTURE	NATURAL RESOURCES & ENVIRONMENT	HOUSING & COMMUNITY DEVELOPMENT	INTERNATIONAL RELATIONS
OCEANOGRAPHY	●	●	●				●	●	●	●	●		●
AGRICULTURE	●	●	●				●	●	●	●	●		●
GEOGRAPHY AND CARTOGRAPHY	●	●	●					●	●	●	●	●	●
HYDROLOGY	●	●	●				●	●	●	●	●		●
GEOLOGY	●	●	●					●	●	●	●		●

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CHAPTER VIII

EARTH RESOURCES SATELLITES

N. A. Frazier and J. G. Stephan

Introduction

The OSSA Earth Resources Survey Program (ERSP) is concerned with the tangible, intangible, and aesthetic resources of the environment in which man lives. For example, Earth resources have been defined as follows:

- Those naturally occurring materials, such as mineral deposits, timberstands, crops, and freshwater and cultural resources which are of value to mankind.[1]
- All conditions on the Earth's surface which are of economic, social, or cultural interest to humanity.[2]

Within this definition of Earth resources, ERSP reflects efforts to utilize Earth satellites and aircraft as sensor platforms to perform what can be summarized as surveying, reconnaissance, or mapping functions. Satellites are receiving the major emphasis but their tradeoff with aircraft is also a part of ERSP. Aircraft are also playing a significant role in RDT&E tasks intermediate to launching a research type of resources satellite.

ERSP is an evolutionary attribute of works in remote sensing of environment and in space technology applications. The former term was first applied in 1961 in a study directed toward the application of a rapidly developing sensor technology to the Earth sciences.[3]

Photographs from hand-held or fixed cameras aboard manned spacecraft constitute one source of information being examined in the evaluation of resource satellites; for example, rectified prints of photographs taken from Gemini 9 were the basis for 1:1,000,000 scale photo-image map covering about 3 x 10^5 square miles of South America.[4] Data from meteorological satellites, particularly in the infrared, and experience in remote optical, microwave, spectral and other measurements with NASA aircraft are also sources of data for assessing satellites as a tool in Earth resources surveys.[5]

Formalized efforts which have subsequently become a part of ERSP were identifiable by Calendar Year (CY) 1965 when the concept was included within NASA's Manned Earth-Orbital Space Program. In CY 1966, Earth resources types of activities were redesignated as the Natural Resources Program. By late CY 1966 or early 1967, the label of ERSP had been adopted.[6-13]

Automated satellites now appear to dominate the thinking within ERSP but opportunities stemming from manned spacecraft within Apollo applications are also to be exploited. A satellite mission devoted specifically to Earth resources has not been flown to date.

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* Superscripts denote references cited at end of this chapter.

Various governmental organizations, e.g., Navy, Interior, Commerce, and NASA are playing roles in ERSP. In total, ERSP includes five applications or disciplines, each with its own objectives. These disciplines are the following:[14]

- Agriculture
- Oceanography
- Geography and Cartography
- Geology
- Hydrology

or, as they appear in References 12, 15, and 16:

- Agriculture and Forestry Resources
- Oceanography and Marine Resources
- Geography, Cartography, and Cultural Resources
- Geology and Mineral Resources
- Hydrology and Water Resources.

Viewing the fundamental functions of ERSP to be those of surveying, reconnaissance, and mapping as pertinent to these disciplines, information on the natural and cultural environments--two basic entities in the sum and substance of the surroundings in which man lives and functions--is to be acquired. Once acquired, this information has many uses and applications, the broad implications of which are implicit in Table VIII-1.

One advantage of satellites derives from their capability to cover rapidly large areas in a synoptic manner. For some applications, the ability to observe large regions offers distinct advantages over aircraft and surface methods. However, the resultant sacrifice in resolution might be detrimental when large-scale details are required.

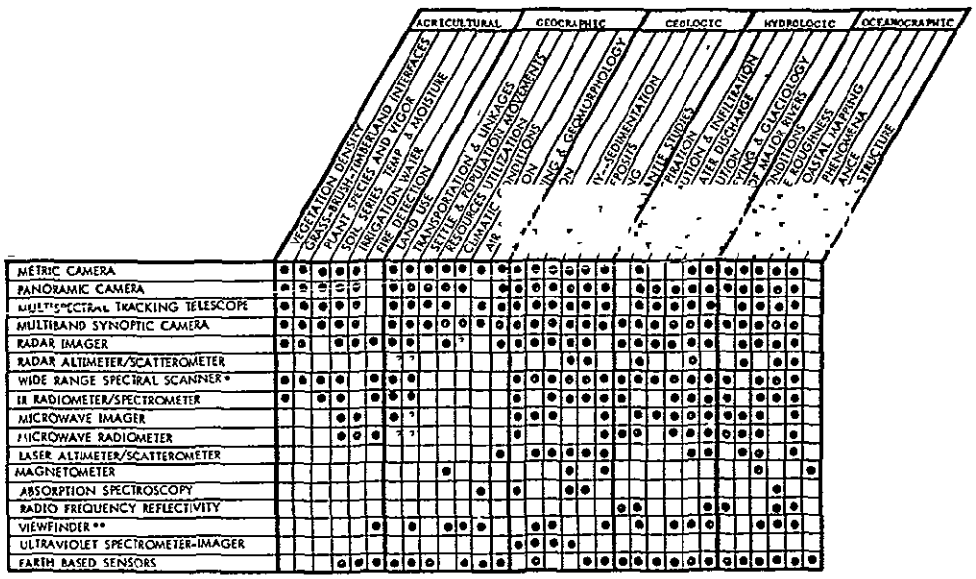
There is no doubt that satellites, as sensor platforms, can collect huge amounts of data relevant to the five ERSP disciplines in a very short time. Still to be clarified are the type of situations in which satellite methods can technically and economically be competitive with or mixed with surface or aircraft data-collection methods. Even in the case of aircraft, problems remain to be solved for example, in the case of interpreting imagery and scanning in nonvisible portions of the spectra or of multiband photography under minimal or realistic ground truth requirements. Through ERSP, problems of sensor specifications and combinations; signature, pattern, and target recognition; and ground truth requirements are being evaluated. As these evaluations take place and as an Earth resources research satellite is launched, the position on the learning curve will be improved, making possible iterative reassessments of the role of Earth resources satellites as an operational tool.

Some idea of the complexity within and among candidate sensor types and potential applications can be gained from Figures VIII-1 and VIII-2. Within several of the sensor types, several alternative sets of specifications are also possible. The task of deciding which combination of sensors will furnish the most useful information for the most beneficial applications is not a simple one.

Figures VIII-1 and VIII-2 do not indicate the degree of complexity of the situation if, for example, _in situ_ data from remotely located or unattended Earth-based sensors are transmitted to Earth resources satellites for subsequent relay to ground stations. For example, in the Interrogation, Location, and Recording System (ILRS) the use of 32,000 separate surface units is envisioned.[5,18,19] One version of ILRS is to be tested on Nimbus spacecraft. A French-U. S. cooperative project, EOLE, is similar in purposes to ILRS.[5]

TABLE VIII-1. EXAMPLES OF POTENTIAL SURVEYING, RECONNAISSANCE, AND MAPPING FUNCTIONS OF EARTH RESOURCES SATELLITES

Potential Types of Information Derivable from Earth Resources Satellites	Application or Use Category				
	Environmental Description & Understanding	Environmental Forecasting/ Quality/Control	Resources Discovery, Development, Management, & Inventories	Patterns & Changes of Land Use	Planning & Execution of Engineering Projects
Tectonics & Structure	X		X		X
Stratigraphy	X		X		X
Magnetic Field	X	X			
Gravitational Field	X				
Erosion/Transport/ Deposition of Sediments	X	X	X	X	X
Volcanoes	X	X	X		X
Glaciers, Ice/Water Boundaries	X	X	X		X
Snow Cover	X	X	X	—	X
Rivers & Drainage Basins	X	X	X	X	X
Physiography/Topography/ Geomorphology	X	X	X	X	X
Cultural Features	X	X	X	X	
Vegetation	X	X	X	X	X
Biological Phenomena & Signatures	X	X	X		
Sea Color/Glitter	X	X			X
Estuaries, Deltas, Bays, Harbors	X	X		X	X
Soil/Sediment Types & Distribution	X		X		X
Ocean Waves, Temperature, & Currents	X	X	X	X	X
Sea Slopes & Levels	X	X			



* 0.32 - 14.0 microns.

** This instrument augments an astronaut's vision with optical power and directional data. The astronaut can utilize the viewfinder by itself or in conjunction with other directional type sensors.

FIGURE VIII-1. EXAMPLES OF SENSOR-TYPE VERSUS POTENTIAL APPLICATIONS (From Reference 1)

(Reference 1: Badgley, Peter C., Childs, Leo, and Vest, William L., "The Application of Remote Sensing Instruments in Earth Resource Surveys" Geophysics, August, 1967, Vol. 32, No. 4, pp 583-601. Reprinted by permission of Geophysics.)

Electro-magnetic Spectrum	Types of Sensing	Surfaces Observed	Surveying, Mapping, or Reconnaissance Functions, Services, or Products	Disciplines Served
λ in microns 0.1 Ultra-violet Visi-ble 1 Near Infrared Long Wave Infrared 10 λ in centimeters 0.1 Radar and Microwave Radar and Microwave 100	Ultraviolet Spectrometry Absorption Spectroscopy Panoramic, Metric, and Multiband Photography Laser Altimetry Solar Incidence IR Radiometry IR Spectrometry Radar Imagery Passive Microwave Imagery Passive Microwave Spectrometry Radar Altimetry	Water Snow Ice Rock Soil Vegetation Horizontal interfaces	Temperatures/surfaces, gradients, anomalies Topography, physical features, geomorphology Sea states and waves Surface geometry of ocean currents Sea slopes and levels Geoid at sea Shallow water and shoals/bottom topography Ice reconnaissance and patterns Ice and water boundaries Beach replenishment and protection Marine transportation and ship routing Sea farming and commercial fishing Erosion, transportation, and deposition of sediments Water management/watersheds and drainage basins, irrigation and water reservoirs, flood surveys and warnings Highway planning and construction Land transportation systems Site surveys Air and sea interactions Volcanoes and geothermal energy Land use/patterns, pattern changes, and inventories Rural and urban planning Vegetation surveys Crops/inventories, diseases and stresses Timber/inventories, diseases and stresses Geological structure and stratigraphy Rocks and soils/types, composition, physical properties Environmental description, forecasting; quality, and control	Oceanography Biology Meteorology Ecology Agriculture Hydrology Geology Geophysics Cartography Geography Geodesy Mineral resources Petroleum resources Agricultural resources Food resources Forestry resources Marine resources Water resources Recreational resources Land conservation Civil engineering Coastal engineering Geological engineering Transportation and commerce

FIGURE VIII-2. EXAMPLES OF POTENTIAL APPLICATIONS OF EARTH-RESOURCE SATELLITES

Goals of ERSP

A fundamental goal of ERSP is stated in the 1966 NASA study of Earth resources requirements:

> To help the world's peoples better understand the reasons for their status and to indicate to them the possible alternatives at their disposal for improving their society.[6]

A 1967 PSAC report quoted in a 1968 NASA document states the goal of ERSP:

> To develop and apply aerospace technology which will assist man in understanding phenomena and thus contribute to the discovery of new resources and the better management of those now known.[14]

In documentation prepared for defense of the 1969 NASA budget, the ultimate goal of ERSP is stated as follows:

> To launch operational satellites capable of collecting large quantities of useful information about conditions at or near the Earth's surface.[15]

The last of these goals is probably the most representative of a general ERSP operational goal, in the absence of information as to which agency would ultimately manage an operational ERSP. All the goals are responsive to the 1958 Space Act because they reflect the peaceful and scientific application of space technology to the achievement of an operational goal.

Objectives of ERSP

Several sets of objectives have been associated with space applications to Earth resources. The topics of these objectives are shown in Table VIII-2 together with number of times each topic appeared and the date and reference of each statement. As would be anticipated, the objectives reflect three types of tasks:

(1) Feasibility, research, and development
(2) Testing and evaluation
(3) Operations.

The relative emphasis, numerically speaking, among the topics of the objectives might not have been expected. Although this emphasis is representative of the amount of attention being given to sensors and other applicable technology in ERSP literature, it does not indicate the gross content of the literature examined on other aspects of ERSP. For example, much more emphasis has been placed on assessing benefits than Table VIII-2 would suggest.

On the other hand, Table VIII-2 indicates the relatively less concern with the "how and in what form" the anticipated ERSP reduced data can or will be made available to and be utilized by the potentially large number of small users. The utility of ERSP to the purposes of large governmental organizations and to fulfilling some of the responsibilities of large entities within these organizations has been recognized.

The potentialities of sophisticated data collection systems are being widely heralded. However, the analysis and dissemination of this potentially overwhelming amount of raw or reduced data are problems awaiting user-oriented research, feasibility, and development tasks.

TABLE VIII-2. PUBLISHED OBJECTIVES OF ERSP

Topic(s) of Objective	Number of Times Mentioned	Reference Number	Date, Reference	Date, Objective
To estimate economic benefits	1	1	1968	
To determine types of resource data best acquired from space	1	7	1965	1966(?)
	2	12		1966
	1	20	1968	
	1	15	1969	
To apply and/or develop sensor technology/S&T capability/ technology and/or space technology	1	7		1965
	2	6		1966
	1	12		1966
	1	14		1968
	1	20		1968
To develop methods based on user oriented interests	1	7		1966 (?)
	1	15	1969	
To determine and/or utilize synoptic and rapid coverage capability	1	7		1966 (?)
To develop data processing and dissemination techniques	1	14	1968	
To evaluate and/or develop platforms most applicable (manned/unmanned/aircraft/ surface/present means)	1	12		1966
	1	7		1966 (?)
	2	14	1968	
To determine role of or utilize advantages of man-on-board	4	7		1965
	2	7		1966 (?)
	6	6	1966	
To improve basic understanding of natural phenomena	1	7		1965

Objectives of ERSP Disciplines

Given first in the following are published objectives of the five ERSP disciplines: agriculture, oceanography, geography and cartography, geology, and hydrology. Following that discussion, sets of "working objectives" are formulated for each discipline for purposes of this study.

Published Objectives of ERSP Disciplines

Agriculture. ERSP objectives in agriculture have been set forth in a program memorandum, titled "Space Applications Programs.[14]

- To identify and measure gross land use to support irrigation planning, land conservation, land reclamation, and the mapping of soils and cultural changes.
- To census crops, timber, and marine and wild life on a national and international bases.
- To improve estimates of crop yield in order to assist in the allocation of resources and governmental/industrial planning.
- To detect crop and timber stress due to drought, disease, fire, flood, and wind.

Within the ERSP, satellite-based sensors are to be applied to agricultural purposes. These sensors, periodically recording comprehensive photographic and other data from space, potentially permit the monitoring and evaluation of various types of agricultural activities within the United States or other given areas of the world.[8,21,22]

Photographic data obtained through aircraft-based sensors are already being used by the United States Department of Agriculture and the Department of the Interior for a broad range of subject matter. These include the following:

- Land-use capability
- Land-use classification
- Land-use changes
- Crop identification
- Crop disease detection
- Crop acreage control programs
- Agricultural development projects
- Agrarian reform programs
- Soil conservation programs
- Soil classification
- Irrigation development
- Flood control surveys
- Water development
- Watershed and hydrologic studies.

Other related subjects include[25]:

- Range management for livestock
- Livestock surveys
- Management of national forests
- Wild life inventories.

Photography has been extremely useful for periodically assessing crop, timber, and wild life resources of the United States in conjunction with ground-truth data obtained by observers on-site or through questionnaires sent to individual farmers. The type of imagery used is still mostly black and white, with scales ranging from 1:10,000 to 1:20,000 and smaller. However, black and white emulsions, as well as color and "false" color films in conjunction with various filters are being increasingly applied to extend the usefulness of the aerial photo. A grasp of the importance of aerial photos in agriculture can be obtained from examination of Table VIII-3.

Current thinking is that various user agencies would be more effectively served through some combination of sensor types on an Earth-orbiting satellite. An advantage often emphasized is that the increased altitude would permit the photography of relatively large areas of land to be surveyed simultaneously in various spectral regions. In the case of photography, it has been estimated that the entire United States could be reduced to 629 photographic frames with a ground resolution of about 10 to 20 feet. The time required to photograph such an area from a satellite platform would be 22 days.[21]

A question that immediately arises concerns the applicability of state-of-the-art methods for acquisition and reduction of data from aerial photography to utilization of photography from space. Because of the vast amount of data recorded in a single photograph, photo-interpretation through traditional methods, which rely very heavily on the time-consuming interpretation and judgment of human operators, will probably have to be replaced by automated means involving computerized equipment, if any overall time advantage is to be realized. Instead of relying on high-resolution imagery in which individual features of a target are recognizable, the routine use of satellite photography or other imagery will call for the automated recognition of so called "target signatures" or "electromagnetic signatures" of any given target.[21,22]

Current and anticipated efforts over the next several years are expected to involve the collection and identification of target signatures in agricultural, as well as other ERSP disciplines, to make the use of large area photographs and other imagery acquired from space feasible. These purposes are currently being pursued using high-flying aircraft equipped with a variety of sensor types[8,24,25], and a number of relevant studies, particularly since 1966, have been made or funded by NASA. No agricultural satellites are planned although the time will come when, according to quotes of former Secretary of Agriculture Freeman, agricultural satellites will be used to detect soil differences; identify crops and types of forest trees; determine disease, insects, and drought; and assess crop stand and vigor to predict production.[26] The outcome of research underway in this discipline could be an Earth-orbiting system which would record remotely various agricultural related phenomena over any desired area, with the resulting data being processed and then disseminated through automated means to the various user agencies.[14]

Oceanography. ERSP objectives in the discipline of oceanography were recently set forth in a 1968 NASA document.[14] These are as follows:

- To support oceanographic research and to assist in economical and safe ship routing by developing the space technology required for the measurement of sea state, surface winds, water temperature, and sea ice

- To improve commercial fishing productivity through the identification of upwellings where fish schools feed and the detection of marine environments preferred by commercially important fish species

- To map submarine topography to a depth of 200 feet and provide bathymetric charts to an accuracy of 1 or 2 fathoms

- To contribute to oceanographical and meteorological research through the mapping of ocean currents and ice cover.

TABLE VIII-3. MAJOR USES OF AIRPHOTOS IN AGRICULTURE BY SUBJECT MATTER[a] AND BY COUNTRY, WORLD SAMPLE (FROM REFERENCE 22)

Country	Major application																																		
	Survey base												Airphoto interpretation																Program base						
	A	B	C	D	E	F	G	H	L	M	N	O	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Australia	x	x	x	-	x	x	-	-	x	-	-	-	x	x	x	-	x	-	-	-	-	-	-	x	-	-	-	-	-	-	-	x	-	-	-
Brazil	x	x	x	-	x	-	-	-	-	-	-	-	x	x	x	-	x	-	-	-	-	-	-	x	-	-	-	-	-	-	-	x	-	-	-
Canada	x	x	x	x	x	-	x	-	-	-	-	-	x	x	x	x	x	-	x	-	-	-	-	-	-	-	-	-	x	-	-	x	-	-	-
Chile	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-
Costa Rica	-	-	x	x	-	-	-	-	-	-	-	-	-	-	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-
Denmark	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
East Germany	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ecuador	x	x	x	-	x	-	-	-	-	x	-	-	x	x	x	-	x	-	-	-	-	-	-	-	x	-	-	-	-	-	-	x	-	-	-
El Salvador	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Guatemala	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Honduras	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
India	x	-	x	-	-	-	-	-	-	-	-	-	x	-	x	-	x	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-
Kenya	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	x	x	-	-	-	-
Mexico	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-
Morocco	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Netherlands	x	x	x	x	-	-	-	-	-	x	-	-	x	x	x	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	x	-	-	-	x
New Zealand	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	x	-	-	-	-	-	x
Nicaragua	x	x	x	-	-	x	-	-	-	-	-	-	x	x	x	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nigeria	x	x	x	-	-	x	-	-	-	-	-	-	x	x	x	-	-	-	x	-	-	x	-	-	-	-	-	-	x	-	-	x	-	-	-
Paraguay	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	x	-	-	-
Peru	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rumania	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	x
South Africa	x	x	x	-	-	x	x	-	-	-	-	-	x	x	x	-	-	x	-	-	-	-	-	-	-	-	-	-	x	-	-	x	-	-	-
Spain																																			
Sudan	x	x	x	-	-	-	-	-	x	-	-	-	x	x	x	-	-	-	-	-	-	-	-	x	-	-	-	-	-	x	-	-	-	-	-
Thailand	x	-	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Togo	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Turkey	-	-	x	-	-	-	-	-	-	-	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
U A.R. (Egypt)	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
United Kingdom	x	x	x	-	x	-	-	-	-	-	-	-	x	x	x	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
United States	x	x	x	x	x	x	x	-	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	x	x
Venezuela	x	-	-	-	x	-	-	-	-	-	-	-	x	-	-	-	-	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yugoslavia	x	x	x	-	-	-	-	-	-	-	-	-	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

(a) Letters in boxheads stand for subject matter as follows:

A Soil classification
B Land use capability
C. Land use classification
D. Land use change studies
E. Natural vegetation
F. Livestock and range survey
G. Soil erosion survey
H. Crop identification
I. Crop estimates
J. Crop disease detection
K. Flood control survey
L. Water development
M. Watershed and hydrologic studies
N. Recreation site evaluation
O. Wildlife habitat studies
P. Wildlife inventory and management
Q. Soil conservation program
R. Irrigation program
S Soil drainage program
T. Agricultural colonization program
U. Agrarian reform program
V Crop acreage control program
W. Reclamation programs

For purposes of planning, an earlier NASA document stated the objectives as follows:[16]

(1) To identify, test, and evaluate those techniques which can be applied to Earth-orbiting spacecraft to provide meaningful and useful oceanographic data relative to the following:

 (a) Economy and safety of ocean transportation

 (b) Location of productive fishing areas

 (c) Development and testing of new techniques for displaying and using synoptic oceanographic data on a global basis which can enhance understanding of the properties and behavior of the oceans.

Much of the work in the oceanographic portion of ERSP has been done under the Spacecraft Oceanography Project (SPOC) within the Naval Oceanographic Office. The SPOC objectives were delineated in three phases:[7]

(1) Feasibility and Research Phase Objectives

 (a) To identify, test, and evaluate those techniques which can be applied in Earth-orbiting spacecraft to provide meaningful and useful oceanographic data

 (b) To establish reliability of spacecraft oceanographic data by comparison with ground truth

 (c) To develop and test new techniques of displaying and using synoptic oceanographic data on a global basis which can enhance understanding of the properties and behavior of the oceans.

(2) Testing Phase Objectives

 (a) To apply procedures and techniques proved feasible during the aircraft testing phase to orbital altitudes to validate in conjunction with ground truth the feasibility of collecting useful oceanographic data

 (b) To refine data handling and display techniques which will be applicable to oceanographic operation problems

 (c) To assess spacecraft orbital and altitude parameters in relation to oceanographic data requirements.

(3) Operational Phase Objectives

 (a) To survey, on a synoptic, worldwide basis, applicable oceanographic features such as surface temperature, sea state, currents, tides, sea ice, and coastal geological phenomena which may be applied to:

 - Increase man's knowledge and understanding of the mechanisms underlying oceanography by exploiting the favorable and unique aspects of spacecraft

 - Develop analytic methods of drawing valid three-dimensional oceanographic inferences from two-dimensional data

- Improve the efficiency, safety, and economy of ocean transportation by optimum routing to avoid weather and ice floes, and to exploit more practically the ice-free seasons of polar and subpolar ports.

The Marine Resources and Engineering Act of 1966 established, at the congressional level, United States goals and objectives in marine activities. Comparison of ERSP oceanographic objectives with the declarations set forth in this Act shows a close correspondence between the two. The goals defined by the Act are as follows:

(1) To develop, encourage, and maintain a coordinated, comprehensive, and long-range national program in marine science for the benefit of mankind to assist in:

(a) Protection of health and property

(b) Enhancement of commerce, transportation, and national security

(c) Rehabilitation of our commercial fisheries

(d) Increased utilization of these and other resources.

The eight national objectives of United States marine activities identified by the Act are:

(1) The accelerated development of the resources of the marine environment

(2) The expansion of human knowledge of the marine environment

(3) The encouragement of private investment enterprise in exploration, technological development, marine commerce, and economic utilization of the resources of the marine environment

(4) The preservation of the role of the United States as a leader in marine science and resource development

(5) The advancement of education and training in marine science

(6) The development and improvement of the capabilities, performance, use, and efficiency of vehicles, equipment, and instruments for use in exploration, research, surveys, and the recovery of resources, and the transmission of energy in the marine environment

(7) The effective utilization of the scientific and engineering resources of the Nation, with close cooperation among all interested agencies, public and private, in order to avoid unnecessary duplication of effort, facilities, and equipment, or waste

(8) The cooperation by the United States with other nations and groups of nations and international organizations in marine science activities when such cooperation is in the national interest.

Potential achievements from spacecraft oceanography are viewed with a great deal of anticipation in light of the vastness of the ocean regions. The problems of attempting synoptic measurement and assessment of time-varying dynamic, physical, and biological phenomena over widely separated areas are extremely difficult to solve. The magnitudes of and relations among many of these phenomena seldom can be determined simultaneously, except over a small region, with any degree of realism. Thus, the potential ability to study these phenomena over widely separated areas at, or approaching, the same time is one source of enthusiasm for the oceanographic discipline in ERSP. If satellites are also used as an Interrogation, Location, and Relay System (ILRS)[5,18,19] for surface-based in situ sensors in remote areas of the oceans, the potential exists for rapid three-dimensional coverage of the oceans.

Numerous studies have been completed and others are underway to examine the eventual use of spacecraft in oceanography and development of marine resources. Experience from aircraft, now used in a rather routine manner for some oceanographic work, is being factored into these studies. Several sensor-types are under investigation including thermal, spectral, microwave, laser, and photographic (multiband, color, false color, etc.). The problem of ground-truth requirements in understanding and interpreting sensor results is also included in spacecraft oceanography. Objectives given previously indicate some of the potential applications which have motivated these studies.

The literature on spacecraft oceanography is becoming quite extensive. The pertinent achievements up to 1967 have been summarized in concise form in a report[28] prepared for the National Council on Marine Resources and Engineering Development.

Satellite altimetry is a recent addition to the potentialities of spacecraft oceanography. Feasibility studies on this application give some cause for guarded optimism. If requirements are met, the oceanographic applications can reap substantial benefits. These benefits hinge upon the ability to determine sea slopes, sea levels, and vertical reference surfaces. These problems have continually plagued oceanographic endeavors. Shortcomings in using geostrophic methods for calculation of volume transport of water might be alleviated, a means of establishing a vertical reference at sea could evolve, geoidal knowledge could be advanced, Earth structure studies could be enhanced indirectly, and sea level datums could be connected across broad expanses of water.[29-32]

Geology. The EROS program of the Department of Interior is directed toward space applications in geology, hydrology, and in geography and cartography.[10,33] Geological objectives of ERSP as stated in 1968 NASA Program Memorada[14] are as follows:

- To identify and classify regional structural and sedimentary features and correlate these with other geophysical parameters
- To identify and monitor dynamic phenomena, such as earthquakes and volcanic eruptions, with the eventual aim of predicting them
- To identify detailed geologic features for geologic maps and thereby contribute to more effective mineral prospecting.

The principles involved in the advantages and problems of Earth resource satellites discussed previously also apply to geology. Structural, stratigraphic, and geomorphic processes in geology generally do not necessitate rapid and synoptic capability potentially afforded by satellites. But the ability provided by satellites to view, map, or study the manifestations of these processes in the minimum number of photographs has distinct advantages. Because of the association between these manifestations and the occurrence of various resources, to be able to photograph and then, almost at a glance, recognize the major structure or structures in a large area is a major assest in resource exploration. Also, if thermal, microwave, and other spectral information for that same area can be obtained simultaneously, interpretive and analytical procedures might be greatly aided.

The study of sedimentary processes-erosion, transport, and deposition of sediments--can benefit substantially from comparatively rapid and synoptic large area coverage. This is because the time changes in the manifestations of these processes can be viewed as a whole rather than as a few isolated details. The importance of sedimentary processes in harbor silting; beach erosion, protection, and replenishment; water reservoirs; and engineering in general is well accepted. Ultimately, details need to be known but the problem and expense of gathering these details, such as with surface and/or aircraft observations, can be greatly reduced if large features are known first. Much the same can be said for practically all aspects and applications of Earth resources satellites.

Geological information has numerous interrelations with other ERSP disciplines wherein information on structure, stratigraphy, geomorphology, or sedimentation is required. Examples include the planning and execution of large transportation projects, coastal engineering projects, or selection of dam sites.

The use of Earth satellites in geophysics as a data relay link between surface-based sensors and central ground stations has been advanced. Seismic and magnetic field data are among the candidates for data relay.

Hydrology. Objectives of this discipline are the following:

- To improve water management for hydroelectric power and irrigation purposes
- To predict and assess flood damage
- To identify new sources of fresh water
- To assess the health and characteristics of inland lakes.

The significance of fresh water as a resource to health and economy is difficult to overemphasize. That this significance will increase with time is an accepted fact, particularly with regard to the natural distribution of the resource in areas of heavy demand. Certainly, the lack or presence of this basic resource has had and will continue to have decided influence on land use patterns and population distribution patterns. Table VIII-4 is an evaluation of remote sensors as tools in hydrology.

In the more developed areas, the potential role of Earth resources satellites in exploration for water probably will be less than will be their role in the broad spectrum of affairs involved in management and utilization of the resource. In unexplored, remote, less developed regions, these satellites offer a potential means for comparatively rapid assessment of water resources. Certainly, they can be valuable tools for guiding and increasing the efficiency of subsequent and more detailed field surface studies.

Satellites as a data collection and relay link between surface-based sensors and ground stations also have applications in hydrology, e.g., in collecting data on rainfall, stream level, and stream flow. This type of information, in combination with relevant satellite imagery given in a timely and useable form for a major drainage basin, is invaluable for flood control, flood prediction, control of irrigation dams, and overall management of water resources.

Geography and Cartography. Objectives in these combined disciplines have been defined as follows[14]:

- To identify natural and cultural features for topographic and demographic maps
- To contribute information important to urban and rural planning.

TABLE VIII-4. EVALUATION OF REMOTE SENSORS AS HYDROLOGIC TOOLS, MARCH, 1968
(From Reference 33)

Remote-Sensor System	General Comments on Potential Value and Use of Remote-Sensor System for Hydrologic Studies
Panchromatic Photography	Panchromatic photography is the most widely used remote-sensing technique because of its availability and relatively low cost. Interpretive techniques are well developed and formal training in its use is available.
Multispectral Photography	Multispectral photography interpretation requires a background of spectral-signature studies of terrain and water features that have not yet been made. Data returns from multispectral systems may be so voluminous that they cannot be readily interpreted. Little work has been done on interpretation for hydrologic purposes.
Infrared Photography	Infrared photography is primarily of value in mapping drainage features and shorelines. The water is always black in a positive print. Some vegetation characteristics are discernible. Its most valuable use is as an adjunct to, but not a replacement for, standard aerial photography.
Color Photography	Color photography, in spite of its built-in spectral redundancy, promises to be a major tool of the hydrologist in many special fields and is sufficiently better for recognition of significant hydrologic features that it may replace panchromatic photography for many uses. The interpretation capability of the potential operational hydrologic users of color photography must be greatly increased. Methods of spectral and density extraction of data are being developed.
Infrared-Color Photography	Color-infrared photography may be superior to standard color photography in some respects. It shows differences in vegetation more clearly and provides a slightly higher contrast on water surfaces. Its general superiority to standard color photography has yet to be proved but it may be highly useful and is worthy of much additional research.
Infrared Radiometry	Infrared radiometry is very useful for sequential measurements of changes in land and water surface temperatures because it is a simple measurement technique and data reduction is simpler than for infrared imagery. Radiometry is routinely used for periodic surveys of near-shore oceanic areas.
Infrared Imagery	Infrared imagery has shown its value as a tool for measuring water-surface temperature and as a means of qualitatively differentiating some terrestrial features. The lack of a simple means of determining emissivity hampers its quantitative usefulness. Analytical techniques for proper use of the reduced data need to be developed.

TABLE VIII-4. EVALUATION OF REMOTE SENSORS AS HYDROLOGIC TOOLS, MARCH, 1968
(From Reference 33)
(Continued)

Remote-Sensor System	General Comments on Potential Value and Use of Remote-Sensor System for Hydrologic Studies
Radar Imagery	Side-looking airborne radar has an all weather capability for coverage of large areas. Its ability to penetrate foliage and accentuate topographic features enhances its value. Water-surfaces are excellent reflectors of microwaves, resulting in a uniform black-tone image. For these reasons stream drainage systems and water surfaces are easy to identify. The black tone precludes measuring the physical, chemical or biologic characteristics of water. Radar may be of value in terrain analysis for ground-water exploration.
Microwave radiometry and imagery	Passive-microwave sensors measure the brightness temperature of terrain and water surfaces. Spatial resolution is lower than infrared systems but radiance is directly proportional to temperature. Probably will find greatest application in oceanic and snow-field mapping.

Relation of Earth Resource Satellites to National Goals

Table VIII-6 represents an attempt to show numerically the relevancy of Earth resource topics in Table VIII-5 to national goals. In the thought processes involved in preparing Table VIII-6, numerous factors were considered. Some of these are described under headings of each national goal. Overall, Table VIII-6 portrays a pseudoquantitative assessment of a complex situation that is replete with interdependent relationships and stripped of the sophistication required to remove or weigh the effects of subjectivity and the many unknowns now associated with ERSP.

One central problem in the transition from the descriptive to a numerical assessment of ERSP relevancy to national goals is that of bookkeeping. The problem stems from what is sometimes referred to as the synergistic aspects of ERSP. The information derivable from a given set of imagery has relevancy to more than one national goal as a result of knowledge, products, and services the imagery ultimately might provide through ERSP working objectives and topics. Succinctly stated, the question is how to distribute this relevancy in a fashion that avoids double accounting. Some simple examples of the multiple uses of potential sets of Earth resource satellite information are given below.

Topographic data and related information on land features are used by the geographer for a multiplicity of purposes, e.g., tracing or planning the economic development of a major drainage basin. The same data are used by the hydrologist in runoff studies for flood control, planning or management of water reservoirs, or the complete hydrological analysis of a major river system or watershed. The geologist will use the same data in geomorphological studies on the origin and genesis of topographic features, the identification and mapping of fault traces, and sometimes in mineral or petroleum prospecting. Water quality and water resources can be included within hydrology, but geographers and ground water geologists also have strong demands for information pertinent to these subjects and even provide the hydrologist with basic information.

Patterns of suspended sediments in coastal region waters can be used by the geologist in studies of sedimentary processes. The coastal engineer will use the patterns for beach protection or replenishment studies. The oceanographer views the time sequence of patterns to study currents. The industrialist examines the patterns for possible information on diffusion of pollutants. The shell fisherman studies the pattern to see if it portrays a silting hazard to fishing grounds. The mineral exploration people might look at patterns in terms of heavy or valuable mineral concentrations.

National Security

The relevancy of Earth resource satellites (ERS) to National Security is considered on the basis that the satellites are a civilian tool to be used in maintaining or expanding national aesthetic and tangible resources base, including the understanding of natural phenomena. In this context, ERS are a potential source of civilian services, products, and technical and scientific capabilities that automatically become available to the military should the need for them arise. These needs cover a broad spectrum, two narrow examples being requirements for intelligence estimates on crops, and for terrain analysis. Related to these, is the information which ERS instrumentation might provide pertinent to arms control and disarmament. If ERS were considered within this framework, relevancy factors would differ greatly from those shown in Table VIII-6. To do so, however, would be akin to appraising a DOD satellite rather than a civilian ERS.

TABLE VIII-6. RELEVANCY OF ERSP TOPICS TO NATIONAL GOALS

ERSP Discipline	ERSP Topical Categories	NATIONAL (FUNCTIONAL) GOALS: NATIONAL SECURITY	INTERNATIONAL RELATIONS	SPACE	AGRICULTURE	NATURAL RESOURCES AND ENVIRONMENT	COMMERCE, TRANSPORTATION, AND COMMUNICATIONS	HOUSING AND COMMUNITY DEVELOPMENT	HEALTH	LABOR	WELFARE	EDUCATION AND KNOWLEDGE	VETERANS AFFAIRS	GENERAL GOVERNMENT
OCEANOGRAPHY	Environmental description, Forecasting - Control	4	3	5	1	4	1	0	1	0	0	4	0	1
	Environmental quality	0	2	3	0	3	1	0	1	0	0	1	0	1
	Food	1	3	5	1	4	0	0	1	0	0	1	0	1
	Coastal engineering	2	1	3	0	2	1	0	0	0	0	1	0	1
	Structures, engineering design	2	1	3	0	2	1	0	0	0	0	1	0	1
	Transportation	3	3	4	1	3	1	0	0	0	0	1	0	1
AGRICULTURE	Land conservation	1	3	3	3	3	0	0	0	0	0	1	0	1
	Land reclamation	1	3	3	3	3	0	0	0	0	0	1	0	1
	Irrigation planning	1	3	3	3	3	0	0	0	0	0	1	0	1
	Crop census	1	3	5	3	0	1	0	1	0	0	1	0	1
	Timber census	1	3	4	3	0	1	0	0	0	0	1	0	1
	Soil description	3	3	4	3	3	0	0	0	0	0	1	0	1
	Wild life census	1	2	3	0	2	0	0	0	0	0	1	0	1
	Crop yield estimates	1	3	4	4	0	1	0	1	0	0	1	0	1
	Crop stress detection	1	3	5	4	0	1	0	1	0	0	1	0	1
	Timber stress detection	1	3	4	4	0	1	0	0	0	0	1	0	1
GEOGRAPHY AND CARTOGRAPHY	Environmental description	3	3	4	3	4	1	0	0	0	0	2	0	1
	Land use, planning, changes	1	3	4	3	3	1	1	0	0	0	1	0	1
	Transportation	2	2	3	1	3	1	0	0	0	0	1	0	1
HYDROLOGY	Environmental forecasting - control	3	3	4	3	4	1	0	0	0	0	2	0	1
	Environmental quality	0	2	3	0	3	0	0	1	0	0	1	0	1
	Water resources	2	3	4	1	3	0	0	0	0	0	1	0	1
	Engineering	2	1	3	1	2	0	0	0	0	0	1	0	1
GEOLOGY	Environmental description, Forecasting - Control	3	3	4	2	4	1	0	0	0	0	2	0	1
	Petroleum, mineral resources	1	3	3	1	3	0	0	0	0	0	1	0	1
	Geothermal energy	1	2	2	0	2	0	0	0	0	0	1	0	1
	Engineering	2	1	3	1	2	1	0	0	0	0	1	0	1

RELEVANCY.

5 = Critically relevant
4 = Fundamentally relevant
3 = Advantageously relevant
2 = Conveniently relevant
1 = Remotely relevant
0 = No apparent relevancy

As shown in Table VIII-6, the environmental description and forecasting portions of ERSP are most relevant to National Security. The descriptions can be in the form of maps, charts, or some other less precise graphical or verbal portrayal of the environmental quantities and qualities. Forecasting or the improved understanding of phenomena prerequisite to taking advantage of a predicted natural or disturbed state of the environment is closely allied with environmental description. Oceanographic portions of this topic are rated higher than the land portions because satellites are potentially without peer for rapid coverage of such vast and relatively unobserved areas.

Relevancy of ERSP objectives to the tangible resources is shown as remote or quite indirect in this appraisal. This is not to question the contributions that the resources make to National Security. Rather, it reflects a situation wherein these contributions arise from the activities and functions of other national goals, e.g., Agriculture and Natural Resources.

The performance of engineering tasks within the DOD structure probably would not be appreciably hampered in the absence of ERS data such as those on ocean waves and sediment transport patterns. If available, such data would constitute a convenient source along with more detailed data from other sources. Under circumstances requiring knowledge of macrocoverage of a pattern or phenomena, the availability of these data could be advantageous. Not to be overlooked is the fundamental relevancy of environmental descriptions and forecasting and the utility of this information to engineering tasks.

In their order of relevance to National Security, the disciplines are oceanography, geography and cartography, hydrology, geology, and agriculture data, which are potentially obtainable from ERS. This is considered realistic and not too surprising, given the premise that satellite platforms are unique in their match of potential capabilities commensurate with the enormity of the oceans.

This national goal can be used to illustrate briefly the difficulties of attempting to estimate the relevancy of space objectives to a national goal as a variable totally independent of other national goals. For example, agricultural space objectives were evaluated as only remotely relevant to National Security with the exception of soils description. Obviously, National Security is not independent of agricultural space objectives and, thus, the Agriculture as a national goal. Soil descriptions obtained by civilian satellites were rated as advantageously relevant to National Security. If technology should permit the physical and engineering properties of soils to be determined from space, this relevancy would increase because of the importance of these properties to mobility. Conceptually, at least for this study, the dependency of National Security for agricultural space objectives is reflected in the relevancy factors of these objectives to Agriculture. The same type of procedural reasoning is applied throughout this section.

International Relations

The use of aerial cameras in the planning and execution of resource program endeavors has increased markedly since World War II. Experiences from these activities combined with similar experiences with other types of airborne sensors attest to the potential utility of ERS as tools for development and management of the resource base of a country. Should signatures from candidates for ERS sensors prove amenable to meaningful interpretation, the relevancy of ERSP to International Relations could be substantial.

The relevancy factors for this national goal stem from the anticipated applicability of satellite platforms to survey relatively large and unexplored areas of the world. Within this concept, ERS data could be of substantial assistance to nations whose territory fits this description and, further, assuming the existence of bilateral, United Nations, AID, or some other form of working agreements. A considerable magnitude of competent manpower and facilities can be visualized if the host countries are to reduce, interpret and use the ERS information in some reasonable time frame.

As shown in Table VIII-6, each ERSP discipline is about equal in relevancy factors. Whether or not this should be true for oceanography is argumentative. However if considered within the context of United States contributions to international programs, such as the International Oceanographic Decade, spacecraft oceanography shares equal status with the other four disciplines.

Conceivably and probably realistically, ERS may be considered politically sensitive and, thus, could have a negative relevancy to International Relations. Specifics are dependent upon national attitudes, world situations, type of sensors, and orbital parameters.

Some of the space objectives in the Space Act of 1958 relate to United States leadership in the peaceful applications of space activities and to international cooperation. Foreign interests in ERS are, thus, perhaps best described under International Relations for purposes of this study.

Soviet interests and awareness of ERS applications and concepts are quite noticeable in their popular press. However, their prominent technical journals are noticeably quiet on the subject and their formal intent is not described until after the fact, all of which is characteristic of the Soviet space program.

K. Ya. Kondrat́yev, rector of Leningrad University and a specialist in infrared physics (particularly in balloon and satellite meteorology), has been a prominent Soviet spokesman on Earth resource surveys in the popular press. Soviet cosmonauts also often refer to satellite capabilities within an Earth resources frame of reference.

Kondrat́yev's remarks cover almost all aspects of space applications currently envisioned in the United States. His interests are quite comprehensive as evidenced by brief mention of TV and infrared imagery, photography in various spectral regions with special mention of IR and microwave imagery. Imagery of all types of surfaces (vegetation, snow, water, etc.) are included. Utilization of this imagery in geobotany, agrobiology, oceanography, geology, hydrology, geography, marine flora and fauna studies, etc., is envisioned. According to Kondrat́yev, his enthusiasm stems from colored photos taken by Soviet cosmonauts. Overall, Kondrat́yev's remarks reflect ERS interests that parallel those of the United States. One exception, however, seems apparent. His perspective seems to emphasize man aboard a spacecraft in Earth resource surveys because man's presence "insures far more reliable control over the operation of an important apparatus and the testing of new instruments".[36,37]

The occasion of the docking of Soyuz-4 and Soyuz-5 spacecrafts has been heralded by the Soviets as marking the assembly and operation of the world's first experimental manned orbital station. The relevance of this accomplishment to Earth resource surveys is suggested from the following abstract from a Soviet newspaper:[38]

> With the help of orbital stations it becomes possible to develop efficient methods of observing Earth from outer space for the purpose of continually watching seasonal and long-term processes occurring on the surface--e.g., accumulation and thaw of snow and ice, precipitation distribution, harvest ripening, the occurrence and spread of plant diseases, and so forth... These methods can be used in geology, geodesy, oceanography, and glaciology to discover mineral deposits and control pollution of rivers and the continental shelf by industrial refuse and effluent.

This sample of recent Soviet pronouncements continues to reflect Soviet attitudes as revealed in 1964 by A. Blagonravov, an international spokesman for the Soviet space efforts. At that time he identified three principal directions of Soviet astronautics, one of which was the mastery of near-Earth space. According to him that mastery probably will be marked by the creation of a manned space station to be served by commuter rockets. Preceding the space station, however, will be meteorological satellites, world TV satellites, navigation satellites, etc.[39]

Earth satellites, as a platform to obtain imagery on the physiographic features and land forms of the Earth's surface are without peer in terms of areal coverage. The utility of this imagery depends upon many variables, e.g., whether the area is well mapped or relatively unknown, whether the imagery is of cartographic quality, what the intended uses are, whether sufficient ground control is available, etc. The use of satellites to establish ground control is discussed in the section on geodesy.

If necessary ground control for the photography is available, the principal problem of mapping is not so much one of mounting a metric camera on a satellite as it is one of knowing and controlling the satellite's orientation to obtain good cartographic quality. Although the point of tradeoff between application of satellites and aircraft for mapping is argumentative and may even loom large in the final evaluations, nobody questions the vital importance of maps and description of the Earth's physical features. One group is of the opinion that mapping from satellites is at least competitive and probably will be cheaper for small or medium scale mapping of near continent size areas where ground control points are sparse or absent.[34] There are also opinions to the contrary including, for example, Reference 35, in which the author examined aircraft versus satellites as a tool for Earth resource surveys.

Improvements in photography that will permit resolution within less than 100 feet from Earth resources satellites has been predicted within the next 10 years. Although it is very desirable that photography from satellites be of cartographic quality, such need not necessarily be the case. In many cases, great utility derives from the relative and approximate positional relationships among the features and phenomena portrayed in a photograph.

Earth resources satellites are being examined as a tool involving land use determinations. Included under studies of these applications are topics such as cultural features, cultural patterns and time changes in those patterns, rural and urban planning, and highway planning. Depending on one's definition of land use, other topics could also be included, e.g., crop land, fallow land, timber stands, and other categories of agricultural statistics.

Working Objectives of ERSP Disciplines

Published ERSP objectives represent a mix of purposes and stages ranging from narrow topics (e.g., ship routing and commercial fishing), through broad statements of purpose, to an operational image. For purposes of this study, it was found convenient to formulate a set of objectives to show ordered parallelism among the ERSP disciplines and objectives (see Table VIII-5). This set, referred to as working objectives, is based on and believed to be consonant with the published objectives and content of the literature examined.

The operational objectives in Table VIII-5 portray the broad purposes and potential for contributions of ERSP. Intermediate and prerequisite to those purposes are stages implied in the RDT&E objectives. The latter are symbolic of tasks and activities ranging from feasibility studies of concepts to the development, launch, and evaluation of research and, ultimately, prototype Earth resources satellites. These RDT&E objectives, which are probably descriptive of NASA's current role in ERSP are quite broad in their scope for purposes of establishing their relation to national goals. For these purposes, ERSP is viewed within the context of the topical categories in the last column of Table VIII-5. These topical categories represent major topics of concern in the operational and RDT&E stages of ERSP.

TABLE VIII-5. ERSP/OSSA WORKING OBJECTIVES

ERSP Discipline	Operations	Research, Development, Test and Evaluation	Topical Categories
OCEANOGRAPHY	To contribute to advancements in understanding of the oceans and of land-ocean interface phenomena To contribute to solutions of applied marine problems of private and governmental pursuits To contribute to more effective development, utilization, and management of marine resources	To determine and assess the contributions of Earth satellites to ERSP oceanographic objectives To apply existing and/or develop necessary technology most contributory to ERSP oceanographic objectives	Physical geodesy Environmental description - forecasting control Environmental quality Food Coastal engineering Structures/engineering design Transportation
AGRICULTURE	To contribute to advancements in capability to improve, monitor, and inventory agricultural resources To contribute to solutions of applied agricultural problems of private and governmental endeavors To contribute to more effective growing, utilization, and management of agricultural resources	To determine and assess the contributions of Earth satellites to ERSP agricultural objectives To apply existing and/or develop necessary technology most contributory to ERSP agricultural objectives	Land conservation Land reclamation Irrigation planning Crop census Timber census Soil description Wild life census Crop yield estimate Crop stress detection Timber stress detection
GEOGRAPHY AND CARTOGRAPHY	To contribute to advancements in geography and cartography To contribute to solutions of applied geographical and cartographical problems of private and governmental endeavors To contribute to more effective development, utilization, and management of land and cultural resources	To determine and assess the contributions of Earth satellites to ERSP geographical and cartographical objectives To apply existing and/or develop necessary technology most contributory to ERSP geographical/cartographical objectives	Environmental description - forecasting, control Land use, rural and urban planning, cultural changes Transportation
HYDROLOGY	To contribute to advancements in hydrology and associated phenomena To contribute to solutions of applied hydrological problems of private and governmental endeavors To contribute to the more effective development, utilization, and management of water resources	To determine and assess the contributions of Earth satellites to ERSP hydrological objectives To apply existing and/or develop necessary techology most contributory to ERSP hydrological objectives	Environmental description - forecasting, control Environmental quality Water resources Engineering
GEOLOGY	To contribute to advancements in geology and associated phenomena To contribute to solutions of applied geological problems of private and governmental endeavors To contribute to the more effective development, utilization, and management of terrestrial resources	To determine and assess the contributions of Earth satellites to ERSP geological objectives To apply existing and/or necessary technology most contributory to ERSP geological objectives	Environmental description forecasting, control Petroleum, mineral resources Geothermal Energy Engineering

Manned space stations were considered in some detail in a Soviet book published by the USSR Ministry of Defense in 1964. Within the general context of Earth resources, reference is made to the use of imagery in the visible, infrared, and microwave regions to increase coverage and accuracy in mapping of the Earth's surface.[40]

Western Europe has given very little official attention to ERS, according to the Director of EUROPESPACE, "despite the enormous benefits which would accure from the use of systems of Earth resource satellites, the selling of services they can provide and their operational management and control".[17] According to him, European governments, in the present economic climate, dismiss as speculative the anticipated benefits when long term investments 20 years into the future are involved.

Space

ERSP's topics in the various disciplines range from advantageous to critical in their relevancy to Space as a national goal and indicate that ERSP is responsive to this national goal. The subgoals of Space considered are those set forth previously in Chapter II. Briefly, these relate to the following:

(1) Potential peaceful and scientific benefits of space
(2) United States leadership in space activities
(3) Space results made available to national defense
(4) Cooperation with other nations in peaceful applications of space
(5) Effective utilization of United States scientific and engineering resources.

Regarding (1) above, ERSP objectives are believed critical to this subgoal. On the average, ERSP objectives were rated fundamental with respect to (2) and ranged from convenient, in the case of Wild Life Census and Geothermal Energy, to critical in the topics dealing with environmental description and food (marine and agriculture) resources. Although (3) is perhaps an indirect result to be derived from the other subgoals, ERSP topics were adjudged to be advantageous with topical relevancies ranging from none to fundamental. ERSP topics are believed fundamental for the most part in matters pertaining to (4). Subgoal (5) has two aspects: (a) the use of manpower to realize ERSP objectives as opposed to other space or non-space goals; and (b) manpower as it is used in current methods for pursuing Earth resource endeavors. In any event, ERSP objectives were rated as advantageous to (5) with ranges from convenient to fundamental, dependent upon the topic.

Agriculture

The importance of world food and timber resources is in the news constantly in one form or another. The significant interdependency with other national goals--e.g., National Security and Health--serves to reinforce this importance. These factors, coupled with the potential of ERS to help meet the need for rapid repetitive coverage over a growing season, are basic reasons for rating agricultural space objectives from fundamental to advantageous in relevancy.

There would seem to be little cause for argument that ERSP agricultural topics are highly relevant to this national goal. The weight to be attached to this relevance at this time is an argumentative topic because it is so critically linked to an as yet undetermined ability to single out, identify, and realistically interpret target signatures from among pictorial or graphical representation of hundreds of square miles of area whose details are fused into a small image. At the present time, it appears that substantial advances are needed. Otherwise, the answers may involve a combination of high-resolution and multispectral imagery, with high-resolution photography used for spot analysis. Use of aircraft as sensor platforms are a strong competitor of ERS.

Geographical space objectives are also quite pertinent to Agriculture. Major agricultural patterns and their changes in the context of land use and their confluence with suburban, urban, and highway use of or encroachments on farm land are among the reasons for assigning an advantageous relevancy to this topic.

Agricultural functions draw greatly upon the types of products and services resulting from environmental description and forecasting. In hydrology, these products and services have to do with watersheds and water supply. In cartography, they relate to the description of topographic or physical features of the Earth's surface, e.g., maps or charts that are basic to numerous endeavors from initial planning to final execution of programs.

Natural Resources and Environment

The relevancy of ERSP topics to this national goal is high. The reasoning behind this relevancy in the context of the interrelationships among the ERSP topics and some of the other national goals are numerous and complex. Any attempt to describe them here would only result in an enigma. Rather, the attempt is made to cite some examples wherein potential types of ERS information supports the purposes of Natural Resources and Environment as a national goal.

One primary purpose of the activities bearing on this national goal is to understand, describe, forecast, and/or control the natural environment, i.e., the parts, sum, substance, and quality of the natural surroundings upon which man depends and in which he lives and functions. Data on numerous factors of the natural environment are collected within the activities serving this as well as some of the other national goals. In broad categories, some of these factors are geological structure; geomagnetic field; topography and physical features; sediment erosion, transport, and deposition; drainage systems; air-sea interactions; surf conditions; and stratigraphy. All are generally described in terms of maps, charts, graphics, photographs, or in words.

Another primary purpose of the activities supporting this national goal is to utilize environmental data. On the basis of iterative and exploratory understanding and description, the totality of knowledge so represented is interpreted and applied to exploration, development, utilization, and management of resources from planning through the final stages by or for innumerable enterprises and pursuits. Involved are forecasts of the state of the environment or predictions on the substance of the environment such as floods, flood control, and water for irrigation; weather in the sense of the influence and interactions with the air-sea interface as they control the weather or climate over land and oceanic areas; the silting of harbors and channels; protection and replenishment of beaches; surf conditions for recreation; favorable areas for commercial fishing; sea-state and currents for marine transportation; and structures favorable to oil accumulation. Estimates of crop yield and of stresses on crops and timber can also benefit from these activities through the Agriculture national goal.

A third primary purpose of this national goal is to be aware of and control the alterations or quality of the natural environment brought about by man's activities and provincial (and sometimes dichotomous and conflicting) interests. This purpose, in more recent times, has gained momentum in the context that the natural environment is not an infinite resource but has finite, undetermined dimensions and capacity. The ability to control changes or depletion of the natural environment ultimately rests upon a better understanding and description of environmental processes.

A fourth and three-part primary purpose of activities serving this national goal is (1) to inventory or analyze either the segments or the sum of past and present effects and patterns of resource utilization and exploitation, (2) to assess the status and changes thus made apparent, and (3) to formulate and implement plans for the future accordingly. In effect, through this continuous confluence of many interacting scientific and engineering, social, economic, and cultural forces, all aspects of the environment are ranked, by action or inaction, directly or indirectly, according to their tangible or esthetic worth. Consequently, the ranking is reflected in various ways, such as some land uses dominating others; some recreational areas being preserved or built while others are degraded; some areas set aside as parks or wildlife preserves while others are not; more, less, or the same emphasis placed on exploration for petroleum and mineral resources; feasibility studies undertaken to develop or apply technology to resource development; tradeoffs among needs for waste disposal and swimming, fishing, or water supply; the assignment of importance to basic understanding of environmental phenomena, maps, and charts, and so forth.

Other National Goals

With the exception of environmental description, ERSP objectives are rated either not relevant or remotely relevant to other national goals. However, this remote relevancy could reflect a very influential relationship under some circumstances, for instance, the effect of crop estimates on grain futures in the business world, the use of sea-state forecasts by transportation industry, and the interactions between ERSP results and the legislative and executive governmental functions.

Although ERSP is an applied program, advancements in basic knowledge, particularly for ocean areas, is a reasonable expectation. A more indirect relationship is the analysis of ERSP results through grants to academic institutions and the subsequent contributions to the educational processes.

Present and Possible Future Courses of ERS Investigations

The following, as Table VIII-7, is a summary of sensors being considered or under evaluation for Earth resource surveys. Where possible, the sensor payload has been correlated with an aircraft or spacecraft mission or experiment. The table is based exclusively on References 14 and 15, especially the former. Payloads and sensors given in the Table span a range of constraints in program options and alternatives dependent upon funding levels. Specifics are given in Reference 14.

TABLE VIII-7. PRESENT AND POSSIBLE FUTURE COURSES OF ERS INVESTIGATIONS

Program, Craft, Experiment, Mission, or Line Item	Description or Purpose	Status Time Frame	Present/Planned Candidate Sensors	Launch Vehicle Requirements
(A) Aircraft Program (1) NASA Convair 204-A (Hope to replace by aircraft in Lockheed P-3A Class)	To fly sensors over test sites and compare data with ground truth information. Operating altitudes between 500 and 15,000 ft.	Now fitted to full capacity and flying. Geological experiments began December, 1964	IR images 8-14μ; UV images 0.29-0.5μ, passive microwave radiometers 9.3-15.8 GHz, 22.2-34 GHz; radar scatterometer 13.3 GHz; multiband camera (near UV, near IR); metric camera 0.4-0.7μ	-
(2) NASA Lockheed P-3A	Same as above but operational altitudes between 1,000 and 30,000 ft. Rapid scan IR spectrometer for studying signatures of geological formations. IR radiometer for studying terrain, ocean areas, and atmosphere.	Became operational in early 1967 with some sensors.	IR image 8-14μ; two-channel IR imager 0.3-5.5μ and 8.0-14μ, variable filter wheel rapid-scan IR spectrometer 6.5-13μ; IR radiometer 10-12μ, radar scatterometers 400 MHz and 13.3 GHz; radar imager 13.3 GHz, passive microwave imager 8.9-9.9 GHz; passive microwave radiometer 1.4, 10.2, 22.2, 22.3, and 32.4 GHz; laser altimeter 0.6439μ--provide altitude information to ±2.5 ft; metric camera RC-8, 0.4-0.7μ; multiband cameras KA-62 (near UV, near IR).	-
(3) USAF RB-57F (?)	Same as above but for altitudes up to and above 40,000 ft hope to simulate conditions more representative of orbital altitudes and above most of the Earth's atmosphere. Do not now understand signatures taken with spatial resolution of 100 to 500 ft., using many types of sensors. This cannot be simulated by degrading low altitude data.	Hope to start data gathering before end of 1969.		-
	(1-3) Aircraft program should develop automated sensor systems which integrate a number of sensors in close simulation of spacecraft requirements. Should also allow users to determine mix of aircraft and spacecraft data required for their responsibilities			
(B) SR&T	Supports line item disciplinary search for user agencies to define and recommend objectives and to develop data analysis technology.			-

TABLE VIII-7. PRESENT AND POSSIBLE FUTURE COURSES OF ERS INVESTIGATIONS (Continued)

Program, Craft, Experiment, Mission, or Line Item	Description or Purpose	Status Time Frame	Present/Planned Candidate Sensors	Launch Vehicle Requirements
(D) Advanced Application Flight Experiments (AAFE)	For developing experiments not preassigned to specific mission because of uncertainty when required technology will be achieved.	Experiments flown when spacecraft can accommodate secondary payloads.	-	-
(E) ERS Limited Objectives Mission (LOM A-E)	To test engineering subsystem and individual sensor systems in Sun-synchronous, high inclination, 126 n. mi. orbits for 14-21 days duration for facilitating design and selection of ERTS sensors. Differs from AAFE in that each LOM is defined and scheduled by date with launch vehicle specified.	LOM-A 1970-1971 LOM-B 1971-1972 LOM-C 1972-1973 LOM-D 1973 LOM-E 1974	-	-
(F) ERS Integrated Systems Experiment	To provide for transition between a research satellite such as ERTS and an operational system. One ISE will be flown prior to each operational series to test the total integration of sensors	1973-1974	Dependent upon results from prior ERS missions	-
(G) Apollo Applications Extended Manned Space Flight Missions	To take advantage of opportunities presented by manned, Earth-orbit missions with regard to Space Applications and to evaluate man's role in the operation of space-borne sensor systems		-	-
(1) First workshop (S-SIV B Wet Workshop)	A 28-day manned mission with revisit capability following unmanned interim period. Total mission duration to permit study of seasonal effects in agriculture, etc.	1971-1972	Metric camera, multiband photography, dual channel imager/scanner, short wavelength spectrometer, electrically scanning microwave radiometer, IR interferometer spectrometer	-
(2) Intermediate Workshops	To combine all experiences from aircraft, unmanned workshop into advanced sensors for optimum response to user agencies.	1974-1977	Earlier flight may include IR temperature radiometer, wide range imager, long wavelength spectrometer, and instrument for radio occultation density measurements Throughout time frame candidate sensors include advanced metric camera, advanced multispectral camera system, multi-channel IR scanner/imager, radar altimeter/scatterometer, passive microwave imagers, microwave imagers, radar imager, absorption spectrometer, advanced IR spectrometer, IR temperature sounders, visible radiation polarization measurements, stellar refraction density measurements, UHF and VHF sferics detection	-
(3) Post-1977	Semipermanent space facility manned by crew of 6-9 to perform real time evaluations in orbit	Post-1977	-	-

TABLE VIII-7. PRESENT AND POSSIBLE FUTURE COURSES OF ERS INVESTIGATIONS (Continued)

Program, Craft, Experiment, Mission, or Line Item	Description or Purpose	Status · Time Frame	Present/Planned Candidate Sensors	Launch Vehicle Requirements
(C) Earth Resources Technology Satellite (ERTS)	To provide transition between laboratory, aircraft, and short duration space flight experiments leading to operational satellite.	-	Based on 1967 GSFC, user agencies, and contractor studies concluded that sensor payload consisting of TV cameras, microwave devices, and a ground-based sensor data collection system may provide for early experimental data requirement. Goals established for this ERTS were: photoimage map of the world, land use map of U.S., agricultural map of U.S., data collection from remote fixed station sites, geological and soil features, sea state measurements.	-
(1) ERTS A-D	Development of technology for definition of an operational ERS system.	Minimum of four flights required at rate of approximately one per year starting in 1971.	-	
(2) ERTS A-B	Stabilized Earth pointing vehicle with attitude control accuracy of $\pm 1^{\circ}$ and 0.05°/sec rate in any direction. RF communication with 20 MHz bandwidth. Minimum of 6000 watt-minutes/orbit available for payload power supply. This technology considered state of the art.			Estimated 1000-lb total spacecraft weight including 300-lb payload. Delta DSV-2L launch vehicle.
(3) ERTS A	Operate in 496 n. mi. Sun-synchronous orbit	ERTS A 1971-1972	Multispectral TV as primary imagery system. Data collection system for remote fixed sites on ground. Sea state monitor.	-
(4) ERTS B	-	ERTS B 1972-1974	Multispectral scanner as primary experiment or perhaps multispectral TV system. Dependent upon ERTS A results.	-
(5) ERTS C-D	Testing of advanced Earth resource sensors and data handling and interpretation system. Payload power may be as high as 20,000 watt-minutes/orbit. RF communication bandwidth 100 MHz.	ERTS C - 1974 ERTS D - 1975	Instrumentation might include imaging radar, HRIR, microwave, and multispectral equipment. Will be influenced by results of ERTS A & B.	Perhaps 3000-lb gross weight spacecraft including 1000-lb payload. Atlas-Centaur (?).

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CHAPTER IX. METEOROLOGICAL SATELLITES

GOAL: To contribute to the exploration, understanding, definition, and prediction of the structure and behavior of the atmosphere

RELATION OF METEOROLOGICAL SATELLITES TO NATIONAL GOALS:

PROGRAM OBJECTIVE AREAS	NATIONAL (FUNCTIONAL) GOALS: EDUCATION & KNOWLEDGE	SPACE	NATIONAL SECURITY	VETERANS	LABOR & MANPOWER	WELFARE	HEALTH	COMMERCE, TRANSPORTATION, & COMMUNICATIONS	GENERAL GOVERNMENT	AGRICULTURE	NATURAL RESOURCES & ENVIRONMENT	HOUSING & COMMUNITY DEVELOPMENT	INTERNATIONAL RELATIONS
SEVERE WEATHER MONITORING	●	●	●				●	●	●	●	●		●
SHORT AND EXTENDED PERIOD FORECASTING	●	●	●				●	●	●	●	●		●
CLIMATOLOGY	●	●	●				●	●	●	●	●		●

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CHAPTER IX

METEOROLOGICAL SATELLITES

R. C. Behn

Introduction

Although concerned specifically with meteorological satellites, this study, of necessity, takes into account some aspects of other satellite programs (e.g., that of the ATS series), which include meteorological experiments. However, other space application programs, principally those involving hydrology and oceanography, that have objectives which relate intimately, but only implicitly, to meteorology, are not considered. Neither are nonmeteorological experiments which are combined with meteorological satellites; or nonmeteorological applications of developments originating from meteorological satellite activities.

In the following discussion, the principal requisite capabilities of meteorological satellites are outlined and related to their basic physical purposes in meteorology; the contributions of these satellites to major types of meteorological activity are described; program objectives are identified and their relation to national goals estimated; and, finally, a summary of projected meteorological satellites is presented.

Goals and Objectives

The United States meteorological satellite program is of particular interest to the general public, and this fact may have led to somewhat exaggerated concepts in the public mind as to the potential of meteorological satellites. However this may be, numerous statements from responsible sources, couched in general terms, attest to the importance and identify the basic objectives of these satellites. A representative group of these statements appears in Table IX-1, and constitutes a commitment of informed opinion to the permanent significance of this space applications program area. This study attempts to quantify this commitment by relating component aspects of the program area to broad national goals.

On the basis of the statements presented in Table IX-1, the following goal can be formulated for meteorological satellites:

> To contribute to the exploration, understanding, definition, and prediction of the structure and behavior of the atmosphere.

Observing Functions[7-16*]

Meteorological satellites for the most part are concerned with the troposphere and lower stratosphere, their principal function being the continuous monitoring on a global scale of a number of atmospheric parameters, and the various meteorological processes which constantly occur. In so doing, they make an important contribution to the overall weather observing effort. In addition to extending and supplementing the data provided by conventional weather observations, which occur over only about 20% of the Earth's surface, satellites are the most important, and in some cases essentially the only, sources of data from the remaining regions.

* Superscripts denote references cited at the end of this chapter.

TABLE IX-1. PURPOSES OF AND ENVISIONED BENEFITS FROM METEOROLOGICAL SATELLITES

	Statement	Source	Reference Number
(1)	"The . space activities of the Unites States shall be conducted so as to contribute materially to [among other things] ..the expansion of human knowledge of phenomena in the atmosphere . ."	National Aeronautics and Space Act of 1958	1
(2)	" ..The Board believes that research meteorological...satellites (as distinct from operational units) will...continue to be of great importance."	Space Science Board (1964)	2,3
(3)	"The goal of NASA is to [among other things]... enrich and expand human knowledge of...atmospheric phenomena	NASA (1965)	1
(4)	"The primary mission of the NASA's meteorological program is to develop and improve space technology in both satellite and sounding rocket systems for use in exploring, understanding, and defining the structure of the atmosphere and for use in predicting its behavior, with particular emphasis on operational application "	Office of Federal Coordinator for Meteorological Services and Supporting Research (1965)	4
(5)	"Earth-orbital missions...would serve to further applications: some of these (...[e.g.] meteorology) would see considerable progress over current achievements."	Space Science Board (1966)	1
(6)	"The general importance of weather satellites is easily recognized."	NASA (1966)	5
(7)	"...We can see immediately the great potential usefulness of a system of orbiting satellites for gathering of weather data . "	Williard F. Libby (UCLA) on "The Worth of the Space Program" (1967)	6
(8)	"The meteorological satellite program is one of the most beneficial of all space activities "	Report to the Congress from the President of the United States. United States Aeronautics and Space Activities 1967.	7
(9)	"The basic goal of the Meteorology Program is to apply space science and technology so that we may better understand the physics and dynamics of the atmosphere and may apply this knowledge for the practical benefit of mankind "	NASA (1968)	8

In the United States, weather satellites constitute a major component of the basic weather observing activity. The Department of Commerce finances, and through the National Environmental Satellite Center (NESC) of the Environmental Science Services Administration (ESSA), manages and operates the National Operational Meteorological Satellite System (NOMSS). This includes an operations center at Suitland, Maryland, and command and data acquisition (CDA) stations at Gilmore Creek, Alaska, and on Wallops Island, Virginia. The Federal Coordinator for Meteorological Services and Supporting Research is currently preparing a long-term plan for NOMSS. However, the Department of Commerce has identified three major operational capabilities desired for the system:

(1) The capability of viewing the atmosphere regularly and reliably on a global basis both day and night and to provide automatic picture transmissions to local ground stations within radio range of a satellite

(2) The capability of sounding the atmosphere regularly and reliably on a global basis to provide quantitative inputs to numerical weather prediction activities

(3) The capability of collecting meteorological data from <u>in situ</u> platforms (e.g., buoys or free balloons), and to relay these and other data to and between weather centers.

Since full attainment of these capabilities is not anticipated until the mid-1970's, interim operational capabilities desired have been defined as follows:

(1) Global picture coverage on a daily basis
(2) Night-time coverage
(3) Automatic picture transmission (APT).

The TIROS Operational Satellite (TOS) series of spacecraft, in general, meets these interim requirements for NOMSS. Two spacecraft (TOS vehicles have been TIROS IX, TIROX X, and the ESSA satellites) are required to be in orbit at all times; One utilizes the Advanced Vidicon Camera System (AVCS) to store daytime imagery for subsequent transmission to the NOMSS CDA stations. It is also equipped with a flat-plate radiometer to measure both reflected solar and long wave terrestrial radiation. Night-time cloud imagery or temperatures are not provided, however. The data received by the CDA stations are relayed to the National Environmental Satellite Center and in turn to the associated National Meteorological Center (NMC), where they have become firmly established as an important input to daily operations. Nephanalyses of the northern Atlantic, North American continental, and northern Pacific areas are prepared and transmitted via the national facsimile circuit for use by forecasting stations; computer-digitized cloud mosaics, requiring some 200 computer hours per month to produce and comprising about 20 transmissions per day, are also distributed via facsimile; cloud maps of tropical areas are being broadcast experimentally via the ATS-1 WEFAX (weather facsimile) equipment to tropical analysis centers; estimates of atmospheric flow patterns in the Southern Hemisphere are made from satellite photographs; and wind data for high levels obtained from satellite photographs are being used experimentally as one of the inputs to the NMC computer-produced tropical upper air analyses. The Air Force Global Weather Central at Offutt AFB also receives the data from the CDA stations and processes it to meet specialized military requirements.

The second satellite is equipped only with APT cameras to provide local area daytime imagery to ground stations throughout the world while they are within radio range of the satellite. These pictures have gained wide acceptance in the United States and abroad. Domestically, they are used, in particular, for providing weather information to overseas flights. They also are used locally for preparing local, area, and flight forecasts. NESC-prepared mosaics of APT data over the United States are furnished to newspaper and television stations and the national and international wire services.

It is NASA's function to develop prototype operational meteorological satellite systems and to procure, launch, and initially check-out in orbit instrumented vehicles on a continuing basis for an established operational system. The first of these responsibilities involves development of sensors and system components having the capability to perform the functions and furnish the meteorological data desired by the meteorological community. Table IX-2 presents the principal existing or potential meteorological satellite capabilities desired, together with their principal basic meteorological purposes.

NASA currently is working toward the provision of several of the capabilities appearing in Table IX-2 which are presently nonoperational or not yet in being. The TIROS M experimental satellite (ITOS prototype) will combine AVCS and APT capabilities in one vehicle and include high resolution infrared radiometers to provide night cloud cover imagery. Infrared spectrometers to provide vertical temperature and water vapor profiles are included among other sensors for development on the Nimbus series of satellites; in situ data collection also is planned.

The ATS series includes as its principal meteorological mission the study of techniques for providing continuous high resolution (of the order of a few kilometers) cloud cover imagery in the visible and infrared ranges. At present, only imagery in the visible band has been attained, with color imagery being provided by the ATS-III satellite. A night television imaging capability is planned for future ATS spacecraft. Another meteorologically related function which has been experimentally performed is the dissemination by APT readout of meteorological facsimile charts relayed to the ATS-I from the ESSA National Meteorological Center. Also, an in situ data collection study (the Omega Position Location Experiment) has been conducted with the ATS-III, using both free floating and fixed surface platforms.

Program Objective Areas

While meteorological satellites contribute only a part of the input to the integrated data base which supports meteorological and climatological activities in general, and the specific importance of this contribution to a particular activity is not always discernible, there are some principal activities to which satellites clearly provide a direct and important input. These are discussed below.

Severe Weather Monitoring. The identification and tracking of weather systems began experimentally with TIROS I in 1960. This surveillance capability permits the early detection and continued monitoring of tropical cyclones, hurricanes, typhoons, and the larger extra-tropical storms. From July, 1961 through mid-September, 1967, some 289 tropical storms were monitored by meteorological satellites. Of this number, 131 were first detected by these satellites. During FY-67, about 600 special tropical storm advisories were issued to meteorological services throughout the world. In some areas, satellites provide almost the only means for monitoring these storms. This is the case, for example, off the western coast of Mexico and Central America, a region infrequently transited by ships, where, on the average, some 10 to 20 hurricanes occur annually.[1,5,10,11,14,21,23]

Short and Extended Period Forecasting. Short term forecasts for periods up to about 48 hours are based, in general, on extrapolations of the observed dynamic behavior of weather systems. Those of macroscale (air masses and frontal systems) require periodic observations (e.g., up to 6 through 12 hour intervals), such as are currently contributed to by satellites of the TOS system. Those of lesser extent and shorter life require more constant observation, such as is currently being provided on an experimental basis by the ATS satellites. These inputs, particularly with regard to the data for the extensive otherwise unobserved areas, contribute importantly to the integrated data base utilized in short-period forecasting. Extended period forecasting requires a suitable mathematical

TABLE IX-2. METEOROLOGICAL SATELLITE CAPABILITIES AND BASIC METEOROLOGICAL PURPOSES[1,5,8-11,13,16-22]

Principal existing or potential capabilities provided or to be provided by NASA Research and Development	Principal basic meteorological purposes
Data Collection and Transmission	
(1) Data storage for subsequent transmission to command and data acquisition (CDA) stations.	(1) Provision of global data to the national meteorological services.
(2) Automatic picture transmission (APT).	(2) Provision of local data to locally established receiving stations throughout the world.
(3) *In situ* data collection (from automatic weather stations, free balloons, etc.)	(3) Effective extension of surface and upper air weather observing networks.
(4) Storage for retransmission, or relay, of *in situ* or other data to or between weather centers.	(4) Effective extension of meteorological communications.
Observation	
(1) Television/photographic cloud cover imaging (by day principally)	(1a) Synoptic analysis. (1b) Research on the dynamics of atmospheric circulations on meso-, macro-, and global scales (1c) Wind field determination.
(2) High resolution infrared cloud cover imaging (by night principally)	(2a-c) Same as (1a-c) (2d) Surface temperature determination. (2e) Cloud-top temperature (provides cloud-top height) determination
(3) Medium resolution infrared mapping (multichannel)	(3a) Synoptic analysis (e.g , delineation of areas of subsidence, inferences as to vertical structure) (3b) Research on the dynamics of atmospheric circulations (e g., as in 3a) (3c) Research on the terrestrial heat balance (3d) Areal atmospheric temperature and water vapor distribution determination
(4) Medium resolution microwave mapping	(4a) Synoptic analysis (e.g., delineation of rainfall areas) (4b) Areal atmospheric water vapor distribution determination
(5) Sferics detection and mapping	(5a) Synoptic analysis (5b) Research on severe storms
(6) Medium spatial, high spectral resolution infrared spectroscopy	(6a) Determination of upper tropospheric three-dimensional water vapor content distributions (6b) Determination of lower stratospheric three-dimensional temperature distributions (provides inferences as to circulations)
(7) Microwave spectroscopy	(7) Determination of three-dimensional atmospheric temperature distribution
(8) Ultraviolet spectroscopy	(8) Determination of three-dimensional stratospheric ozone distribution
(9) Optical (high-precision star tracking)/microwave(slave satellite) refraction measurement	(9) Determination of three-dimensional atmospheric density distribution

model of the atmosphere, adequate computers, and the necessary quantitative atmospheric data on a global scale. At present, fairly good numerical techniques and adequate computers exist, and planetary scale models of the atmosphere are under rapid development. The data required include the pressure, temperature, humidity, and wind vectors, all as functions of latitude, longitude, and altitude. Initially, a horizontal grid spacing of about 500 kilometers, and several (3-9) levels below 15 kilometers are considered to be necessary. Observations must be global and on a 12 to 24 hour repetitive schedule. In the opinion of the National Academy of Sciences, for example, satellite technology offers the only practicable method of providing this world-wide flow of quantitative meteorological data. When achieved, it is anticipated that forecasts of about 2 weeks in winter and somewhat longer in summer will be possible. Present efforts toward these capabilities include the Nimbus and ATS programs for the development of spectrometric and other sensing techniques, and in situ data collection capabilities; and the World Weather Program of the World Meteorological Organization (WMO). The last consists of a World Weather Watch (WWW) and a Global Atmospheric Research Program (GARP). The WWW is a permanent international global observing program, in which satellites will make important contributions, principally to provide the type data required for extended-range forecasting. GARP, sponsored also by the International Council of Scientific Unions (ICSU), is to be similar to the World Weather Watch but devoted to research, particularly on the general circulation. It is to be conducted during the 1970's.[1,5,7,8,10,12-14,20,22-24]

Climatology. Because meteorological satellites enlarge the meteorological data base, especially for relatively unobserved regions, they also benefit climatology, which involves the integration of weather events over time. Climatological data have applications in many areas of human activity.[5,13]

In addition to these principal activities, meteorological satellites are envisioned as having potential for other meteorological activities. Most important among these may be future weather control. Such a capability, at least on the meso-, or macroscale, requires a much more thorough understanding of the atmosphere than currently exists. It is expected that meteorological satellites will provide data necessary to that understanding. In addition, it is envisioned that satellites can serve as platforms for the conduct of weather control activities, as for example, the concentration of, or interference with solar radiation, either locally or regionally, by the injection of foreign material into the terrestrial space environment.[1,5,22]

Meteorological satellites are also envisioned as having potential in air pollution control. It is expected that the remote sensing capabilities on these satellites, particularly in the infrared range, may be applicable to the study of atmospheric contaminants.[1,17,20,22]

Program Objectives

Analysis and experience have shown that this melange of functions and applications is best provided by a system comprised of automated spacecraft in two orbital configurations: Near-Earth (order of 1000 kilometers) Sun-synchronous, and geosynchronous. To supplement these, automated satellites in near-Earth equatorial orbits, and manned vehicles in a variety of orbits, or maneuverable among various orbits, are envisioned. These mission classes, each leading to differing vehicle characteristics and/or launch capability requirements, constitute suitable program objectives for the purposes of this study.[1,8,10,11,17,21,22]

Near-Earth Sun-Synchronous Satellites. This is the principal class of current meteorological satellites. Global coverage is provided by vehicles in circular near-polar orbits (about 82 degrees). Suitable choice of orbital parameters permits surveillance of the globe by a single vehicle at 12-hour intervals, at constant local times for each location, the orbital precession being synchronous with the motion of the right ascension of the Sun. The TIROS Operational Satellites (TOS) and the Nimbus vehicles are of this class. Observations of nearly all meteorological parameters and phenomena for which sensing capabilities exist or are planned will be made. These observations must be made at high and medium spatial resolutions and high spectral resolutions.

Geosynchronous Satellites. While generally considered as basic to an optimal meteorological satellite system, this orbital class nevertheless is supplementary to the Sun-synchronous group of satellites. Geosynchronous satellites have important, but restricted, purposes, these being principally the provision of continuous high resolution cloud cover imagery to monitor short-lived mesoscale disturbances and the global circulation. *In situ* data collection and data relay are planned as additional functions using these satellites.[9-11,13,26]

Near-Earth Equatorial Satellites. Automated meteorological satellites in equatorial orbits at altitudes from 1000 to 2000 kilometers constitute a corollary orbital class. Observations probably will be similar to, but not as numerous as, those conducted with near-Earth Sun-synchronous satellites. Areal coverage up to about ±30 degrees from the equator can be obtained, and a single spacecraft can provide frequent (of the order of 100 minutes) repetitive observations. Thus, the near-equivalent to continuous monitoring of short-lived mesoscale disturbances would be provided.[8,17]

Manned Meteorological Satellites.[15,17,22] About 600 useful color photographs were obtained during 1966 on manned Gemini flights 10, 11, and 12. These enabled meteorologists to identify mesoscale features with a resolution of about 70 meters. Also, a number of meteorological experiments are planned for Apollo Applications Mission 1A, and would involve day and night photography, infrared spectroscopy, infrared and microwave radiometry, and sferics. These activities are indicative of probable future manned meteorological satellites. The attributes of such vehicles were reviewed in 1966 by the Panel on Meteorology of the NASA Space Station Requirements Steering Committee. Man is envisioned as having three basic tasks: observation, operation, and maintenance.

With regard to the observation function, the trained scientist can discriminate, analyze, interpret, and correlate various phenomena; this function cannot be automated, since it involves the falculty of judgment. Unusual, highly localized, or short-lived phenomena can be identified and scientifically or operationally exploited. Also, data handling and usefulness can be optimized by the onboard real-time monitoring of sensor output for the purpose of screening out erroneous and redundant data.

The scientist can adjust and calibrate (the operation function), as well as routinely operate instrumentation. Unsophisticated, or the opposite, very complex instruments can be used, and comparison tests of similar instruments can be made. Controlled and cooperative experiments can also be conducted.

Lastly, man can repair and service instrumentation (maintenance function), both within and immediately external to his vehicle, and by excursion to an unmanned vehicle of a meteorological satellite system. The latter function places a requirement on the manned station for a major excursion capability, both with regard to altitude and to orbital inclination.

Because the optimum altitudes with regard to resolution and viewing from polar orbits (of the order of 1000 kilometers) introduce the requirement for protection for both men and equipment from the effects of the Earth's radiation belts, it is envisioned that tasks for the early manned meteorological satellites should be such that they can be performed in low-altitude, low-inclination orbits. Ultimately, manned vehicles in geosynchronous orbit are hypothesized.

Relation to National Goals

The estimation of the relevancy of a program objective (orbital class of satellites) to a national goal is aided by considering meteorological applications to which a class of satellites contributes. In some cases, it essentially reduces to the estimation of the relevancy of an application to that goal. These estimates of relevancy are contained in Table IX-3. Supporting discussion follows.

National Security[4,5,8,13,27]

The critical dependence of military activity upon the weather is axiomatic. Battles certainly, campaigns probably, and wars conceivably, have been decided by the effects of the elements. The United States Navy maintains a professional, predominantly marine, meteorological service, while the United States Air Force has a large global activity, the Air Weather Service. The Air Weather Service also provides most of the meteorological support required by the United States Army, although the latter engages in some specialized meteorological activity. These services cooperate with, and in part depend upon, the efforts of the United States Weather Bureau and other meteorological entities within ESSA. Strategic planning can be heavily dependent upon climatological information; operations and tactics relate critically to the availability and quality of severe weather advisories and short- and extended-period forecasts; certainly future weather control capabilities will have an important impact upon all weather-related military matters.

In addition to their general contribution to the integrated meteorological data base, the particular importance of meteorological satellites to these military matters includes their capability to provide weather data from otherwise denied or unobserved areas. This information not only is important to the meteorological support of military operations, but constitutes intelligence as to the existing weather-related capabilities of hostile forces. Satellites also are important for the Automatic Picture Transmission (APT) service which can be provided directly to forces in the field. As of FY 68, the reception of APT transmissions by field units in Vietnam was planned.

Sun-synchronous vehicles are most important for the performance of these functions, although geosynchronous satellites, being less vulnerable to hostile action, as well as providing some storm-warning capability, may be of primary importance in specific situations. Automated equatorial satellites would be of value in special cases. A high degree of relevancy for a manned meteorological satellite is not apparent.

International Relations[5,7,13,25]

The atmosphere being a global medium, the concepts and importance of meteorology are international in scope. Long accepted in principle, this characteristic is now more recognized in practice, as is evident, for example, from the present day activity and influence of the World Meteorological Organization (WMO). Meteorological satellites have contributed, and, in the future will contribute more importantly, to this development. For instance, the use of near-Earth Sun-synchronous, geosynchronous, and, possibly, near-Earth equatorial satellites is planned for the World Weather Watch and GARP.

The United States has been an active participant in this international activity, and the principal source of the contributions from meteorological satellites. Satellite data are distributed on the international weather circuits, some exchange of satellite data has occurred between the United States and the U.S.S.R., and APT service from United States spacecraft has been made available to users throughout the world. At the beginning of 1968, there were over 300 stations in at least 45 countries which were receiving pictures by means of this technique. A special office within ESSA provides a focal point for planning United States participation in the World Weather Program. This

TABLE IX-3. ESTIMATE OF RELEVANCY OF SATELLITE METEOROLOGY TO NATIONAL GOALS

Program Objective Area	Program Objectives (Orbital Classes of Satellites)	National (Functional) Goals								
		National Security	International Relations	Space	Agriculture	Natural Resources and Environmental	Commerce, Transportation, and Communications	Health	Education and Knowledge	Government
	Near-Earth Sun-synchronous[a]	5	4	5	3	3	4	3	3	3
Severe Weather Monitoring	Geosynchronous[a]	5	3	5	3	3	4	1	3	3
Short and Extended Period Forecasting	Near-Earth equatorial[a]	3	2	3	1	1	3	1	3	2
Climatology	Manned, various orbits or maneuverable	2	2	2	2	2	2	2	3	2

Relevancy Rating:

5 Critically relevant
4 Fundamentally relevant
3 Advantageously relevant
2 Conveniently relevant
1 Remotely relevant
0 No relevancy

office has been preparing, among others, a study of the feasibility of a system of satellite-tracked balloons for that program. It follows that the meteorological satellite activity of the United States makes an important contribution to the maintenance of a favorable national image, and to the promotion of a peaceful world community.

Space[1,5,13]

The successful conduct of space-flight missions depends heavily upon the availability of comprehensive and reliable weather reports and forecasts. In particular, manned space flight requires constant surveillance of global weather conditions throughout a mission period. Meteorological satellites have been instrumental in meeting this need, particularly, with regard to the rapidity of data acquisition, and to coverage of the relatively unobserved southern hemisphere. This is expected to be a continuing function for these automated spacecraft.

The satellite capabilities developed for the study of the terrestrial atmosphere on a global scale are envisioned as becoming useful to the study of the atmospheres of other planets. It is probable that such studies would be confined to automated vehicles.

Agriculture[4,12, 13,20]

Much agricultural activity is intimately related to the weather and heavily dependent upon adequate weather observations and forecasts. To a considerable extent, this dependency is serviced by storm advisories, and by general weather forecasts, sometimes tailored so as to cater to agricultural needs. Such forecasts utilize the integrated data base to which meteorological satellites contribute.

More specialized agricultural data and forecasts usually are of a micrometeorological nature, concern local areas only, or consider one or a few meteorological parameters. Such activity does not relate significantly to meteorological satellites. On the other hand, the potentialities for agriculture of any weather control capability are large, and such a capability conceivably may be satellite-dependent.

Natural Resources and Environment[4,13]

Weather influences recreational activities; may have important, even vital, effects upon fish and wildlife; and intimately relates to the matter of forest fires. Data and forecasts for these use areas, even if specialized, as are some fire-weather forecasts, derive for the most part from the integrated meteorological data base. However, as in the case of agriculture, potentialities for these use areas of any weather control capability are large.

Because the function of meteorological satellites is, in itself, an environmental science service and because meteorology is not specifically relevant to other environmental science services except as may be implicit in its relevancy to other national goals, the relevancy of meteorological satellites to environmental science services as a National goal is not recognized in this evaluation.

Commerce, Transportation, and Communications[4,510,12-14,20]

Adequate weather observations and forecasts can be vital to transportation activities. In the case of ground transportation, general weather forecasts, supplemented by severe weather advisories, suffice for the most part. The same is true in general for marine transportation, although, here, forecasts may be more specialized, and the dependence on meteorological factors is more vital. Meteorological satellites play a more direct role in marine transportation, however, since they provide data from the otherwise relatively unobserved ocean areas. These data are obtained principally with the Sun-synchronous vehicles, but geosynchronous satellites can contribute significantly to severe weather warning activities. Near-Earth equatorial satellites could be of importance also, in part because they would perform a specialized tropical-storm warning function. In providing data from the tropics, they would be doing so for relatively unobserved, largely oceanic areas, and for a region for which weather forecasting techniques are less well established than are those for higher latitudes. Meteorological satellites also provide an APT service to surface vessels and isolated stations in marine areas.

Of all transportation activities, aviation has the most critical need for meteorological data. Here, however, the required weather support is highly specialized, relates often to short time periods, specific routes or local areas, and is provided by a well established specialized weather service activity. The APT service provided by weather satellites is becoming increasingly important for these purposes, however. Required weather support that is more extensive in time and space derives in part from the general weather service and the integrated meteorological data base. Here again, however, the contribution of meteorological satellites for oceanic areas is increasingly important.

Many commercial activities are heavily dependent upon adequate weather forecasts, either to permit proper physical operation (e.g., pipe lines, construction activities), or for planning of marketing or similar activities. In general, however, except for their contribution to the integrated data base, meteorological satellites do not contribute significantly to satisfying these requirements.

Housing and Community Development

Except for the construction aspect mentioned under Transportation and Commerce, there appears to be no relevancy of meteorology in general, or meteorological satellites in particular, to this national goal.

Health

Although weather and climate relate importantly to health considerations in general, there appears to be little direct cause and effect relationship between the aspects of meteorology considered here and health matters. Two exceptions present themselves. One is the climatological data base, to which meteorological satellites contribute, and which no doubt has direct application to related medical studies. The other is the field of air pollution control, one principal motivation for this activity being a concern for health. Meteorology makes important contributions to the control of air pollution, and it is envisioned that satellite remote sensing techniques will become useful to the study of atmospheric contaminants.[1,13,17,20,22]

Labor and Manpower and Welfare

There appears to be no significant relationship of meteorology in general, or meteorological satellites in particular, to these national goals.

Education and Knowledge

In that they will increasingly provide important contributions to mankind's basic knowledge of the atmosphere, meteorological satellite programs can be considered as being designed in part to generate fundamental knowledge.

Veterans

There appears to be no significant relationship of meteorology, in general, or meteorological satellites, in particular, to this national goal.

General Government

In that weather and climate, and thus meteorology, bear upon all human activity, they bear upon the general activities of government. Improvements in meteorological capabilities presumably result in increased efficiences in weather-affected or weather-dependent activities. In this manner, meteorology and meteorological satellites relate indirectly to the general activities of government.

Future Flight Program

Table IX-4 provides a summary of those meteorological satellites, or satellites that include meteorological missions, which either have been approved for launch, are in the planning stage, or have been proposed. There appears to be some overlap of objectives among the programs of the last category. Where information was lacking, entries to the table have been omitted. Some discrepancies in detail were noted with regard to data from multiple sources. In general, the latest, or what appeared to be the most authoritative data were used. While the information contained in the table is believed to be reasonably correct, it is not categorically authoritative.

TABLE IX-4. METEOROLOGICAL SATELLITE POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES

Satellite(s)	Status	Expected Launch Date	Mission Objective	Spacecraft Description	Mission Profile	Launch Vehicle	Launch Site	References
			Near-earth Sun-synchronous Satellites					
TOS-G (ESSA-9)	Approved	Feb. 1969	To provide daylight global remote cloud-cover imagery and reflected short-wave, and terrestrial long-wave radiation data	Sensors Two AVCS and recorders Flat-plate radiometer Weight - 325 kg Power - 20 watt solar battery	Inclination-78.8° retrograde Altitude - 1390 km Period - 113 5 min. Cartwheel mode spin-stabilized	Delta	ETR	1,9,16,28-31
TOS-H (ESSA-10)	Approved	CY-1969	To provide local daylight cloud-cover imagery to local APT ground stations while within radio range of the satellite.	Sensors Two APT camera systems Weight - 130 kg Power - 28 watt solar battery	Same as TOS-G	Delta	WTR	1,9,16,28,30,31
TIROS-M (ITOS prototype)	Approved	May 1969	On an experimental basis, to provide day/night cloud-cover imagery and both local and remote read-out capabilities, and reflected short-wave and terrestrial long-wave radiation data.	Sensors Two AVCS and recorders Two APT camera systems Two HRIR (high resolution infrared) radiometers Flat-plate radiometer Solar proton monitor Weight - 272 kg Power - 110 watt solar battery	Inclination-82° retrograde Altitude - 1390 km Period - 113 min. Earth oriented, gyro-magnetically stabilized	TAD (Thrust augmented Delta)	WTR	1,9,10,14,16,22,28,30,31
ITOS-A	Approved	Sept. 1969	Same as TIROS-M, but on an operational basis.	Sensors - same as TIROS-M Weight - 280 kg Power - 110-150 watt solar battery	Inclination-79° retrograde Altitude - 1390 km Period - 113.5 min. Orientation and stabilization same as TIROS-M	TAD	WTR	1,9,10,14,28,30,31
ITOS-B	Approved	First half CY 1970	Same as ITOS-A	Same as ITOS-A	SAME as ITOS-A	TAD	WTR	1,10,14,30,31,
ITOS-C	Approved	Second half CY 1970	Same as ITOS-A	Same as ITOS-A	Same as ITOS-A	TAD	WTR	1,10,14,30,31
ITOS-D and E	Approved	Second half CY 1970				TAD	WTR	1,10,14,30,31

TABLE IX-4. METEOROLOGICAL SATELLITE POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES (Continued)

Satellite(s)	Status	Expected Launch Date	Mission Objective	Spacecraft Description	Mission Profile	Launch Vehicle	Launch Site	References
				Near-earth Sun-synchronous Satellites				
Nimbus-B2 (Objective, description, profile essentially that for original Nimbus-B)	Approved	May 1969	To develop earth-oriented meteorological satellite primarily designed for exploration of the structure of the atmosphere, including vertical profiles of selected parameters; to develop *in situ* data collection capability; and to develop other advanced techniques.	Sensors IDCS (image dissector camera system) HRIR radiometer Interferometer spectrometer Satellite infrared spectrometer IRLS (interrogation, recording, and location system) MRIR (medium resolution infrared) radiometer Solar ultraviolet monitor Weight - 630 kg Power - 200 watt solar battery, SNAP-19 50 watt radioisotope thermoelectric generator	Inclination-80° retrograde Altitude - 968 km Earth-oriented, 3-axis stabilized, with yaw axis aligned with local vertical	Thor-Agena	WTR	8-10,16,20,30, 31
Nimbus D	Approved	March 1970	Same as Nimbus-B2	Sensors IDCS HRIR radiometer Selective chopper radiometer Backscatter ultraviolet radiometer Cloud altitude spectrometer Filter wedge spectrometer Interferometer spectrometer Satellite infrared spectrometer IRLS Solar ultraviolet monitor Sferics detector Improved control system (including gravity gradient technique) Improved data transmission system Weight - 560 kg Power - 200 watt solar battery (no SNAP-19)	Same as Nimbus-B2	Thorad-Agena	WTR	1,9,10,16,22, 30,31

TABLE IX-4. METEOROLOGICAL SATELLITE POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES (Continued)

Satellite(s)	Status	Expected Launch Date	Mission Objective	Spacecraft Description	Mission Profile	Launch Vehicle	Launch Site	References
			Near-earth Sun-synchronous Satellites					
Nimbus E and F and subsequent vehicles of the Nimbus follow-on series	Planned	Beginning CY-1972 with one launch per year thereafter (No. 1 alternative program); after Nimbus F one launch in each of the years 1975, 1976 and 1978 (No. 2 alternative program); Nimbus F launch 1974, next launch no sooner than 1978 (No. 3 alternative program)	To provide improvement in Sun-synchronous near-Earth oriented meteorological satellites.	Sensors to be determined Weight - 453-680 kg Power - 200 watts Improved control systems utilizing both active and passive techniques	Inclination-80° retrograde Altitude - 1100-1390 km Period - 108 min. Earth-oriented, three-axis stabilized with yaw axis aligned with local vertical	Thorad-Agena	WTR	8-10,22,30
World Weather Watch Satellites	Proposed	2 - CY-1973 1 - 1974, 2 - 1976, 1 - 1977 (No. 1 alternative program); 2 - CY-1973, 2 - 1976 (No. 2 alternative program); 1 - CY-1973, 1 - 1976 (No. 3 alternative program)	To provide additional Nimbus type satellites in support of WWW and GARP.	Same as Nimbus follow-on series	Same as Nimbus follow-on series			8,9

TABLE IX-4. METEOROLOGICAL SATELLITE POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES (Continued)

Satellite(s)	Status	Expected Launch Date	Mission Objective	Spacecraft Description	Mission Profile	Launch Vehicle	Launch Site	References
TIROS Follow-on Satellites	Proposed	1 - CY-1973, 1 - 1976 (No. 1 alternative program), 1 - CY-1973 (No. 2 alternative program); 1 - CY-1975 (No. 3 alternative program).	To develop advanced polar orbiting integrated systems experiments satellites in support of NOMSS. (See ASMS)	Will incorporate state-of-the-art advances achieved by Nimbus program. 1973 flight to include operational infrared temperature profile sensors. 1976 flight to include operational microwave sounders.				8
			Geosynchronous Satellites					
ATS-E	Approved	May 1969	Among other missions, to develop applications technology basic to the making of continuous high resolution meteorological observations, more specifically, to test techniques for day/night cloud cover imaging from geostationary orbit, and to test meteorological data collection and transmission via the VHF band.	Weight - 370 kg Power - 125 watts	Hohmann transfer ellipse to geosynchronous orbit; circularization and inclination removal by kick motor integral to vehicle. Three-axis gravity-gradient stabilization to accuracy of ±3°	Atlas-Centaur	ETR	1,9,16,30,31
ATS-F and G	Planned	1969-1975	Among other missions, to test stabilization techniques to provide, a pointing accuracy of ±0.1°, useful, among other purposes to meteorological sensors and in fixing positions of *in situ* platforms to test meteorological TV and infrared sensor performance	Weight - 500-1000 kg Power - 200 watt solar battery	Approach trajectory under study. Stabilization techniques under study.			1,9
ATS-K and M	Proposed	1974-1987	Among other missions, to develop pointing technology to extreme accuracies (1 7 x 10^{-8} radian) required for, among other purposes, extremely high resolving Earth-oriented sensors.					1

TABLE IX-4. METEOROLOGICAL SATELLITE POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES (Continued)

Satellite(s)	Status	Expected Launch Date	Mission Objective	Spacecraft Description	Mission Profile	Launch Vehicle	Launch Site	References
				<u>Geosynchronous Satellites</u>				
ATS Meteorological Satellites	Proposed	2 - CY-1974, 2 - 1976 (No. 1 alternative program); 1 - CY-1974, 2 - 1976 (No. 2 alternative program); 1 - CY-1975 (No. 3 alternative program).	Constrained to the development of meteorological techniques, including night cloud cover imaging and determination of the vertical structure and dynamics of the atmosphere.	Based upon ATS-1 and ATS-3 technology.	Dual launches in one calendar year to provide one satellite over Atlantic ocean, one over the Pacific. Dual missions to be correlated with multi-discipline ATS satellites.			8
Synchronous Operational Meteorological Satellite (SOMS)	Proposed	CY-1971	To provide cloud-cover and low resolution radiation data from geosynchronous altitude.					1,8
Advanced Synchronous Meteorological Satellite (ASMS)	Proposed	1 - CY-1971 1 - 1974 (No. 1 alternative program), 1 - CY-1971 (No. 2 alternative program); 1 - CY-1972 (No. 3 alternative program).	To develop advanced geosynchronous integrated systems experiments satellites (see TIROS follow-on satellites).	Sensors To provide daytime cloud imaging with revolution of 0.8 km. To provide night cloud imaging with revolution of less than 3.0 km. Other Weight - 220-450 kg Power - 100-200 watts	Location approximately 90° W.			1,8,9
Advanced Synchronous Operational Meteorological Satellite (ASOMS)	Proposed	Beginning about CY-1975	To provide operational counterpart of ASMS					1

TABLE IX-4. METEOROLOGICAL SATELLITE POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES (Continued)

Satellite(s)	Status	Expected Launch Date	Mission Objective	Spacecraft Description	Mission Profile	Launch Vehicle	Launch Site	References
				Near-Earth Equatorial Satellites				
Low Altitude Equatorial Satellite	Proposed	One launch in each of years 1974-1977 incl. (No. 1 alternative program); one launch in each of years 1975, 1976, 1977 (No. 2 alternative program), 1 - CY-1975, 1 - 1977 (No. 3 alternative program).	To obtain tropical meteorological data on larger scale than possible from geosynchronous vehicles, and more frequently than possible from Sun-synchronous vehicles.	Based upon Nimbus/TIROS technology	Low altitude, very low inclination			8
				Manned Meteorological Satellites				
Apollo Applications Program Satellites APP-A	Proposed	To provide a first simultaneous set of atmospheric measurements from orbit, to conduct a comparative evaluation of 14 complementary and mutually supporting experiments, other nonmeteorological objectives	Sensors Infrared spectrometers and radiometers, microwave radiometer sferics detector, day-night cloud-cover cameras Instrument weight-1000 kg Power - 1500 watts		Inclination - 90° Altitude - 350 km Duration - 14 days			1,9,22,31
APP-B								31

TABLE IX-4. METEOROLOGICAL SATELLITE POSSIBILITIES AND ASSOCIATED LAUNCH FEATURES (Continued)

Satellite(s)	Status	Expected Launch Date	Mission Objective	Spacecraft Description	Mission Profile	Launch Vehicle	Launch Site	References
			Manned Meteorological Satellites					
APP-C	Proposed		To provide a first simultaneous set of atmospheric measurements from geosynchronous altitude; communication missions.	Sensors: Infrared spectrometers and radiometers; day-night cloud cover cameras. Instrument weight-1000 kg Power - 1500-2000 watts	Duration - 14 days			9
APP-D								1
			Other Satellites					
International Application Satellite (IAS)	Approved	Dec. 1969	To study wind field near 27000 ft. in Southern Hemisphere by means of data collection from <u>in situ</u> balloon platforms (EOLE project).	French-built satellite FR-2 Weight - 98 kg	Inclination - 50° Altitude - 697 km Gravity stabilized	Scout	WI	10,30,31
Unified Space Application Satellites (USAMS)	Proposed	Late 1970's	To provide a single satellite (or a minimal number of satellites) to replace Nimbus follow-on and later ATS spacecraft, and to serve all application disciplines.	Not yet determined	Various, to include low-altitude and medium altitude polar, and geo-synchronous orbits.			1,9

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CHAPTER X. GEODETIC SATELLITES

GOAL: To determine the Earth's size and shape, its surface geometry and dynamics, and to use this knowledge for practical applications

RELATION OF GEODETIC SATELLITES TO NATIONAL GOALS:

	NATIONAL (FUNCTIONAL) GOALS												
PROGRAM OBJECTIVE AREAS	EDUCATION & KNOWLEDGE	SPACE	NATIONAL SECURITY	VETERANS	LABOR & MANPOWER	WELFARE	HEALTH	COMMERCE, TRANSPORTATION, & COMMUNICATIONS	GENERAL GOVERNMENT	AGRICULTURE	NATURAL RESOURCES & ENVIRONMENT	HOUSING & COMMUNITY DEVELOPMENT	INTER-NATIONAL RELATIONS
GEOMETRIC GEODESY	●	●	●					●		●	●	●	●
GRAVIMETRIC GEODESY	●	●	●					●		●	●	●	●
APPLICATIONS SUPPORT	●	●	●					●		●	●	●	●

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CHAPTER X

GEODETIC SATELLITES

A. G. Mourad

Introduction

In 1962, the subcommittee on Space Science of the Committee of Science and Astronautics of the United States House of Representatives recommended that NASA prepare, organize, and assume management of a multi-agency program to satisfy the nation's scientific and defense requirements in satellite geodesy. Accordingly, the National Geodetic Satellite Program (NGSP) was established under NASA/OSSA for the broad purposes of establishing a unified world reference system and determining the gravity field of the Earth.[1*] More recently, a wider scope program, the NASA Geodetic Satellite Program (GSP), has been established with NGSP as a component.[2,3,4,5] Most of the work in satellite geodesy to date, except for classified defense work, has been accomplished under these two programs. Table X-1 shows the magnitude of effort of the U.S. Government and other organizations participating in GSP.

Goals and objectives of NGSP and GSP are described immediately below. Within the two major goals that have been identified, specific objectives in three areas have been established. Following the discussion of these goals and objectives, their relationship to national goals is examined.

Goals and Objectives

Two major NGSP goals related to geometric and physical geodesy were first identified in 1964. These goals are as follows:[1,2,5,6]

(1) To establish a Unified World Datum that will permit connecting existing local datum systems within ±35 feet to a common geocentric reference frame based on Earth's center of mass and axis of rotation

(2) To provide a refined description of the worldwide variations of Earth's gravitational field by determining the set of "J" gravity coefficients which characterize them through 15 degrees and order to an accuracy such that they contribute no more than ±3 mgal rms error to determination of 12° x 12° mean anomalies at the Earth's surface.

With the near fulfillment of the NGSP goals, a more specific and expanded GSP goal has been defined in accord with the above two goals and with the addition of a third relative to applications. An overall GSP goal can be formulated on the basis of the literature:[3,4] To determine the Earth's size and shape, surface geometry and dynamics and to use this knowledge for practical applications in Earth and space sciences.

The emphasis now is to exploit the results of the NGSP studies and to explore the utility of geodetic satellite technology for application to solid Earth sciences and marine sciences using, for example, satellite altimetry, interferometry, and other advanced methods.[4] Such applications will impose higher accuracy goals, than those stated above, by an order of magnitude or better.[2,5,7,8]

* Superscripts denote references cited at the end of this chapter.

TABLE X-1. OBSERVATION STATIONS PARTICIPATING IN THE GEODETIC SATELLITE PROGRAM[5]

Network	Total Number of Participating Sites (to 1967)	Observation Instrumentation
NASA Space Tracking and Data Acquisition Network (STADAN)	19	Cameras: MOTS-40 Goddard Range and Range Rate System (RARR)
U.S. Navy Observation Network (TRANET)	34	Doppler beacon receiver System
U.S. Air Force Observation Network	27	Cameras: PC-1000 Photometer Laser Ranging System
U.S. Coast and Geodetic Survey (USC&GS)	25	Cameras: BC-4
U.S. Army Observation Network	19	Cameras: BC-4 (just for PAGEOS) Range Transponder System (SECOR)
NASA Special Optical Network (SPEOPT)	16	Cameras: MOTS-40, MOTS-24, PTH-100, BC-4 Laser Ranging System
International Participants	18	Cameras: Several Types Laser Ranging System
Smithsonian Astrophysical Observatory (SAO)	27	Cameras: Baker-Nunn, Geodetic 36 Laser Ranging System
Total	185 sites	

Within the above goals, three major areas of interest, each with associated objectives, have been identified. These are listed below:[1,5,8,9]

(1) Geometric Geodesy

(a) Datum connections

(b) Control point locations

(c) Islands and inaccessible areas connection

(d) Fiducial point locations

(e) Marine control point locations

(2) Gravimetric Geodesy

(a) Gravity harmonic coefficients determination

(b) Gravity anomaly location

(c) Satellite orbital prediction

(3) Earth-Science and Application Support

(a) Marine sciences including marine geodesy/ precise ship positioning, oceanography and satellite altimetry

(b) Solid Earth geophysics

(c) Space sciences.

Description of Goals and Objectives

Satellites can be used in two different modes to fulfill geodetic objectives:

(1) geometric mode, wherein simultaneous or nonsimultaneous measurements are made of distances and/or directions to the satellite(s) from several ground stations, and station positions are determined with respect to the orbit by triangulation or trilateration techniques

(2) dynamic mode--observations of satellite motion are compared with predicted motion and results are analyzed to determine the coefficients of the gravity field from different satellite inclinations or from resonant satellites. The type of satellites used in geodesy are described later in this report under "Technical Considerations and Forecasts".

The nature and status of related satellite geodesy programs and techniques are discussed below.

Datum Connections

The purpose of making datum connections is to tie together the major world geodetic datums in a common reference system. Surface geodetic methods have historically been used to establish national geodetic datums. However, these methods are not effective or economical for tying large continental areas that are separated by ocean expanses. Geodetic satellites have proved to be the best means available for this purpose.

Control Point Locations

Control points are fixed points whose coordinates (latitude, longitude, and height) have been established by geodetic means to a specific accuracy depending on the intended use and purpose. The GSP accuracy goal is ±35 ft in a geocentric reference system. These points are distributed throughout the country forming a geodetic network on which maps, surveys, and various engineering projects are based. Each country requires at least one reference point on which the geodetic datum can be based. These points have been established by surface geodetic methods. Satellites are an efficient means by which these control points could be verified and additional control points could be established in each country and tied to the same world reference system.

Islands and Inaccessible Areas Connection

Several islands and large inaccessible land areas have been mapped by surface geodetic methods independently. Errors of one mile or larger were not uncommon. Satellites have proven to be the most accurate method for connecting remote islands to the world reference system. Accuracies approaching those for control points have been predicted; however, actual figures have not as yet been published.

Fiducial Points Location

Another objective of satellite geodesy is to provide a multitude of fiducial points in a Unified World Reference System for 1:25,000-scale mapping.[9,10] Aerial photogrammetry at present provides such fiducial points. The use of satellite photogrammetry also has the potential for establishing such points with much Earth coverage on a worldwide scale.[8]

Marine Control Point Locations

Marine control points are points of fixed coordinates (latitude, longitude and depth) established on the ocean floor to a specified accuracy. Only one has been established in the world (Pacific Ocean).[11] Satellites provide the only means, present and near future, for their accurate establishment, particularly in the deep oceans. These points will be as important to ocean surveying, mapping, and exploitation as their counterparts on land are for similar applications.

Gravity Harmonic Coefficients Determination

Satellite orbital data are used to develop an expression of the Earth's external gravity field through a series of spherical harmonics. The coefficients of the various harmonic terms are functions of orbital perturbations caused by variations in the shape of the Earth and its mass distribution. Although surface gravity methods can provide such determinations, the lack of surface data on a worldwide basis is a limiting factor. Satellites, on the other hand, can overcome these limitations as well as furnish information of high accuracy on the lower order spherical harmonics.[1,12]

Gravity Anomaly Location

Satellite data analysis can provide information on large-scale variations in the Earth's gravity field, giving average value of the gravity for 10° x 10° squares, or about 600 x 600 mile squares, worldwide. Surface methods which can provide detailed information on small gravity anomalies can also provide information on large areas but at higher cost and over much longer periods of time. To date, about 25% of the Earth's surface has adequate gravity coverage. Satellites, thus complement surface gravity methods.

Satellite Orbital Prediction

Precise knowledge of the orbit of satellites can play a key role in the geodetic determination and description of the gravity field and station locations. Conversely, refinements in these geodetic constants lead to improved predictions of satellite orbital elements required for space endeavors.[8,10,13-15] Effective utilization of satellites in Earth and marine sciences (e.g., determination of mean sea level) would require that satellite position accuracy[16-18] be better than ±1 meter.

Marine Sciences

Satellite geodesy can contribute to three major areas of marine sciences:

(1) Precise ship positioning--Ship positioning is required for many ocean operations, particularly bathymetric surveying and mapping, and marine geodesy. Accurate and continuous ship positioning to better than ±100 feet is required for many open ocean areas. There is no single system at present that can satisfy such a requirement. Satellite technology, if coupled with other appropriate methods, have the greatest potential for meeting the requirements.[1,8,19]

(2) Marine geodesy--The use of satellites in marine geodesy is of prime importance, particularly for establishing marine control points and marine geodetic standards and for developing the precise measurement technology so badly needed for all accurate ocean work. Accuracies of point locations of the order of ±35 to ±100 feet in a geocentric coordinate system are required for many operations.[19] Surface and airborne methods can satisfy requirements up to 100 miles from shore. Beyond, and particularly in the deep ocean, it appears that only satellites may have the necessary potential. Satellite application to the area of marine geodesy is in its infancy.[1]

(3) Oceanography and Satellite Altimetry--Oceanographic measurements that can benefit from satellite geodesy are those related to determination of ocean currents, ice motion, ocean tides, and mean sea level. In general, if oceanographers could have a position accuracy of ±600 feet on a continuous worldwide basis, many additional useful results could be derived from the oceanographic data being collected.[18,19]

The most critical determination of oceanographic measurements is that of mean sea level. For such determination, an accuracy of better than ±1 meter in mean sea level is required. There are no direct means at present to measure mean sea level. Satellite altimetry offers the only means for such measurements provided that satellite position in its orbit is known to better than ±1 meter and the averaged measurement of altitudes over the oceans is made to an accuracy of few centimeters. Theoretical studies indicate that satellites can be used to make such measurements, but this remains to be seen in a practical demonstration. Geos-C planned for launching in late 1970 will have a satellite altimeter on board.[72] Several investigators and proposals are being evaluated for their contribution to satellite altimetry.[7]

Solid-Earth Geophysics

There are several problems associated with solid-Earth geophysics that satellites can help to solve.[20] These problems include horizontal and vertical land motions along fault zones, Earth tides, tsunami warning, continental drift, convection currents, and internal density distribution. Satellites offer a means to monitor the horizontal and vertical land motion with respect to a fixed Earth-centered coordinate system. Such knowledge is valuable for prediction of earthquakes and release of stress and energy in Earth. Earth tides and tsunami warnings are also possible if satellite altimetry could achieve the accuracy required for determination of mean sea level. Similarly, application in continental drift studies is also possible if the needed capabilities relative to accuracy and monitoring of continental motion over a long period of time with the same system can be provided. The use of satellite interferometry offers potential for detecting and monitoring continental drift.[21] The expansion of the gravity potential in spherical harmonics is already useful for determination of convection currents and internal mass distribution of Earth.[8,10,22]

Space Sciences

Space science programs of interest include improved orbit prediction, atmospheric structure investigation, precise location of satellites, and study of gravitational effects.[23-25] Accurate prediction of the orbit of satellites far into the future is of considerable practical, economic, and scientific value for many applications including the determination of satellite location for magnetic field study and precise navigation.[26] The increased knowledge of the gravity field helps to distinguish perturbations due to gravity from those caused by atmospheric drag. Such information contributes to improved orbital prediction, knowledge of the atmosphere, measurements of tidal gravity, satellite altimetry, etc.

Relation to National Goals

The objectives and goals of the Geodetic Satellite Program can be related to the following national goals (see Table X-2):

(1) National Security

(2) Space

(3) Education and Knowledge

(4) International Relations

(5) Natural Resources and Environment

(6) Transportation and Commerce

(7) Agriculture

(8) Housing and Community Development.

TABLE X-2. ESTIMATE OF RELEVANCY OF SATELLITE GEODESY OBJECTIVES TO NATIONAL GOALS

OBJECTIVE	SUBOBJECTIVE TOPICS	NATIONAL SECURITY	SPACE	EDUCATION AND KNOWLEDGE	INTERNATIONAL RELATIONS	NATURAL RESOURCES AND ENVIRONMENT	TRANSPORTATION AND COMMERCE	AGRICULTURE	HOUSING AND COMMUNITY DEVELOPMENT
GEOMETRIC GEODESY	Datum Connection	5	5	4	3	0	0	0	0
	Control Point Locations	3	4	3	1	3	2	2	3
	Marine Control Point Locations	5	5	4	3	3	1	2	1
	Island and Inaccessible Areas Connection	5	5	1	1	2	0	0	1
	Fiducial Points Location	3	3	1	1	4	3	3	4
GRAVIMETRIC GEODESY	Harmonic Coefficient of Gravity Field	4	4	4	0	0	0	0	0
	Gravity Anomaly Location	3	2	3	0	3	0	1	0
	Orbit Precision Determination	4	5	4	1	0	2	1	3
APPLICATION SUPPORT	Marine Geodesy/ Precise Ship Positioning	4	4	4	3	3	2	3	1
	Oceanography/ Satellite altimetry	4	4	4	3	3	2	3	0
	Solid-Earth Geophysics	2	4	4	2	3	1	3	1
	Space Sciences	4	4	4	4	3	1	0	0

RELEVANCY RATING:

5 Critically Relevant
4 Fundamentally Relevent
3 Advantageously Relevant
2 Conveniently Relevant
1 Remotely Relevant
0 No Apparent Relevancy

National Security

Geometric geodesy contributes most to national security because of the nature of the various geometric subobjectives and their relationship to the effectiveness of modern weapon systems.[27-30] The datum connection is perhaps most important; however, the various geometric subobjectives are closely interrelated and thus all have higher ratings than other subgoals as is indicated in Table X-2.

One goal of satellite geodesy is aimed at the establishment of a unified world geodetic system. This also implies better determination of the size and shape of Earth and connecting the major world geodetic datums in a unified reference system. The military services have established several geodetic systems including the USAF 1958, the U.S. Army 1959 and the DOD 1960 world geodetic systems (WGS 60).[28,31,32] These reference systems resulted primarily from surface and airborne measurement techniques. However, early satellite findings played a major role in such determinations. For example, the 1958 Vanguard satellite furnished the first major result relative to the flattening of the Earth ($\alpha = 1/298$).[5]

The first world geodetic system using satellites was established in 1963. Twelve tracking stations were connected together, worldwide, to an accuracy of ±150 feet. This system is called the Unified World Reference System. In 1967 42 stations were connected, 20 stations within ±60-foot accuracy. Errors as large as 2000 feet in some of the earlier locations were discovered. The ultimate accuracy goal of these stations is ±35 feet in an Earth-centered coordinate system.[1]

The first satellite designed for geodetic purposes was launched by DOD in 1962.[11,30] However, formal use of a satellite in meeting the requirements for the geometric objective began with the introduction in 1962 of the NGSP under NASA's management in participation with the military services. Since then, satellites have been used to meet the requirements of both the military and the scientific communities in making further refinements of the parameters of the world reference system. The U.S. Army, for example, is involved in tying several islands in the Pacific Ocean to the world reference system using satellite SECOR techniques.[29,32] Other ocean islands and inaccessible areas must also be connected in the future. A requirement still exists for refinement of the WGS 60 to insure that future defense and civilian needs can be satisified.[28,31,33]

Currently, large portions of the geometric geodesy objective are being accomplished under the NGSP. An interim global geodetic system will be prepared by NASA using all the data accumulated through calendar year 1968 by the cooperating agencies, including the military.[1] It appears that the remaining portions of the geometric geodesy could be completed in the early 1970's except for the establishment of marine control (reference) points. From the point of view of national security, these could become of primary importance for Polaris and advanced Navy missile systems such as Poseidon. If "hard target" capabilities are required for such systems, marine control points must be accurately established and tied to the same world reference system. In this event, satellites would be the only means for satisfying requirements in establishing these points in the open oceans to provide both horizontal and vertical coordinates (satellite altimetry and astrogeodetic and gravimetric), and final completion of the geometric geodesy objective could go much beyond the 1970's.[19]

Fiducial point locations are also important for the control of large scale mapping which in turn is important for national security. At present, aerial photogrammetry provides most of the control necessary for such mapping. It is expected that, once satellite techniques are perfected, they can compete with aerial methods to provide maps on a world-wide basis. Furthermore, with increased accuracy of these methods and reduction in their cost, satellites could provide a capability for engineering scale surveying and mapping. Because of the wide satellite coverage, it has been estimated that cost of assembling stereo pairs of photographs obtained by satellites is orders of magnitude less than that obtained at present by conventional means for the same area. This is in addition to the time saving.[6]

Gravimetric geodesy is by no means of lesser importance than the geometric geodesy. These two are interdependent and improvement in one contributes greatly to the other. For example, determination of the position of a satellite in its orbit depends on many factors including accurate location of ground tracking stations, detailed description of the gravity field, and orbital parameter analysis.

The importance of gravity harmonic coefficients to national security is indicated by the DOD decision to classify such data in 1966. These coefficients are necessary to define the large scale variations in the gravity field which have a significant effect on missile flight paths.[28] At present, satellites offer the best means for such determinations. This subobjective is expected to be achieved in the early 1970's at which time surface gravity measurements, on a world-wide basis, should also be completed by the DOD.[24]

The satellite application support subobjective is already contributing directly to national security through improved orbital predictions, precise location of satellites, and gravitational effects as described previously. This subobjective should also be satisfied in the early 1970's.

Solid-Earth geophysics, one of the application subobjectives, may contribute indirectly to national security by providing data leading to solution of geophysical problems which might be encountered in military operations. However, it may be better to obtain some of the information required for such purposes by surface methods.

The marine sciences application subobjective was formulated more recently than the other two. Of special interest are the areas of marine geodesy, precise ship positioning, satellite altimetry for direct determination of mean sea level, and oceanography. The requirements of marine geodesy and precise ship positioning and the role of satellites in satisfying them has been examined in detail.[19] They are expected to become as important to national security as land geodesy has been in the past. Satellites appear to be the only effective means by which sufficient accuracy can be provided on a world-wide basis for advanced marine weapons systems and anti-submarine warfare.[19,26,34] Requirements involving satellites are yet to be formalized. Several studies for this purpose have recently been started.[19,35]

In oceanography, several satellite applications are possible.[10,18,36,37] These are related to improving positioning capabilities for oceanographic work and advanced altimetry measurements for direct determination of mean sea level, both of which have been discussed previously.

It is apparent that the marine sciences will require satellite geodesy technology and application with associated activities extending well into the 1980's.

Space

If there is one NASA program that can meet all the Space Act Goals, the GSP is truly that one. Through this program the first of several geodetic satellites was launched, ensuring early U.S. leadership in this field. The first outstanding satellite geodesy results, evidence of the pear shape of the Earth and polar flattening, were deduced from the analysis of Vanguard I orbit in 1958. These results, obtained in only a few months, settled the scientific argument concerning the Earth's shape that has been carried on for centuries. Since Vanguard I, many other satellites have been launched and several new facts concerning the Earth and its gravity field have been discovered.

Through the GSP it has been made possible for the U.S. not only to be first in achieving many dramatic results, but also to maintain leadership of all nations in space programs. GSP results have been achieved through effective utilization of U.S. scientific and engineering resources as well as through peaceful cooperation with other nations. Table X-1 indicates the degree of international participation in the GSP program. Moreover, GSP results are available for national defense purposes, fulfilling another of the space goals. In fact, DOD actively participates in several continuing military observation programs, as shown in Table X-1.

The relevancy factors in Table X-2 indicate the importance of the GSP. Satellite geodesy provides the opportunity, for the first time, to meet the geometric geodesy objectives (considered unachievable by other techniques) with high precision and in a short time. The ability of satellites to accurately locate control points and to tie various datums and connect islands and remote areas separated by thousands of miles is critically relevant to geodesy. The fact that the size and shape of the Earth is being determined to an accuracy unattainable by other means also speaks well for the indirect benefits derived from the GSP.

In the application-support area, further measurement precision is being achieved and several firsts can be claimed. For example, satellite interferometry studies may eventually settle the questions of continental drift and polar wandering. Through satellite altimetry, direct determination of mean sea level may eventually be possible to a few centimeters. These are just a few examples of what the GSP can contribute.

Satellite geodesy contributes directly to the space objectives in cost reduction of space related functions and activities. For example, direct benefits from satellite observations are improved satellite orbit prediction, reduction in satellite tracking costs resulting from better knowledge of the Earth and its gravity field, and reduction in position fix costs (e.g., for oil and mineral exploration in remote areas). These direct benefits are estimated at $4 to $10 million per year.[6]

The increased accuracies in satellite geodesy measurements offer support in space operations, particularly as follows:[8]

- Better location of tracking stations in a geocentric reference system, particularly those on islands and remote areas. Satellite geodesy offers the only accurate means for their determination. The location of Apollo ships in the world ocean is another application.

- Increased orbit prediction capability. Orbit prediction is of great importance for space operations, particularly for interplanetary probes, Earth satellites, and missiles.

- Development of better orbit-analysis techniques. Satellite geodesy often involves dealing with methods of observations and with reduction, analysis, and adjustment of data. The refined methods that have been developed are applicable to other planetary orbits and make possible the extraction of much additional information from data obtained.

- Calibration of tracking systems. The equipment at GSP tracking stations has been calibrated to very great accuracy. These stations could serve for the calibration of other tracking systems.

Education and Knowledge

In Table X-2, the application-support objective received the highest rating, with the geometric and gravimetric objectives being rated about equal in contributing to education and knowledge. This is primarily because geometric and gravimetric systems are already operational while the technology for achieving application and support goals is being, or is yet to be, developed.

The scientific community has always sought high accuracy in geodetic measurements; however, in the past, the status of these goals has been subject to one requirement imposed by other higher priority goals such as national defense. In any case, historically, the determination of size and shape of Earth, datum connections, establishment of control points, etc., have contributed to science and education.[1,13,15,19,38-40]

Satellite geodesy involvement in application-support is highlighted primarily in the new areas of marine geodesy and precise ship positioning and direct mean sea level determination. The technology needed for these purposes has never been fully developed. The growing national and international ocean-oriented interests and activities will force greater emphasis on marine geodetic requirements which are considered to be heavily dependent upon satellite technology for their solution.[19,40] With the developing technology for precise geodetic measurements, particularly for the establishment of marine control points on a world-wide basis, satellite geodesy should make direct contributions to marine sciences, such as oceanography, and provide a basis for microstructure oceanographic surveys.[10,19,35,36,41]

One of the current unanswered scientific questions relates to movement of the continents (continental drift) which is of the order of a few centimeters per year. Detection of such movements will require highly sophisticated measurement techniques and may be possible by employing lasers aboard satellites and interferometric techniques.[8,17,21,33] Earthquake prediction, Earth-tidal measurement, and horizontal and vertical movement in the Earth structure could also benefit from satellite geodesy techniques if the necessary accuracy in satellite-position determination can be improved by an order of magnitude. Solution of these problems would represent scientific and/or academic breakthroughs. Never before has solid-Earth geophysics received such attention: satellite application is becoming more prevalent in the geosciences because it provides a practical means for obtaining data leading to solutions in many problem areas.[8,10,19,20,22]

International Relations

Since geodesy deals primarily with the measurement of the size and shape of Earth, it is clearly a true international science. Satellite geodesy, with its intercontinental ties, world-wide tracking and orbiting capabilities, etc., contributes to international affairs primarily through scientific and educational programs that involve the cooperation of many nations including the Soviet Union. Recent international congresses, specifically involving satellite geodesy, are a true example of such cooperation. The solution of many geodetic problems and the completion of several satellite-geodesy goals will depend greatly on the degree of international cooperation that can be achieved in the next few years.[23,38,42-44] Table X-1 indicates to some extent the degree of international cooperation. As of 1967 a total of 18 sites employing cameras and laser ranging systems were participating in the NGSP.[5]

Perhaps the major satellite-geodesy contribution to international affairs will come through the establishment of marine geodetic control points, development of marine geodesy and precise ship-positioning capabilities, and improvements in ocean-measurement technology. More important, marine control points, once established, could become the cornerstones for international boundary line identification, a means for settling international-property disputes, and a basis for accurate ocean mapping.[19]

The application of satellites in support of objectives in solid-Earth geophysics has already been demonstrated on an international scale through the IGY and Earth upper-mantle programs. Similar activities should continue well into the 1980's.[8,20]

Natural Resources and Environment

Successful exploitation of natural resources require that accurate and detailed maps be available. Since geodesy forms the basis on which maps are developed, the sub-objective relating to fiducial-point locations by satellite geodetic techniques for the construction of 1:25,000 detail maps is considered of the highest relevance here. At present, maps are developed from data obtained from gound-based and airborne systems. Satellite geodesy could result in more economy and speed in the determination of fiducial points than present methods and therefore is expected to play a major future role in such activities.[6,8,24,45] In the proposal stage, four low cost satellites are visualized for use in every day surveying, mapping, highway, and civil engineering projects.[45] Such a system, which in concept could become operational by the mid-1970's, is expected to provide the necessary accuracy, and will possibly be more economical than presently used surface methods.

For the economical exploitation of ocean resources, accurate marine control points and precise ship positioning are among the major requirements associated with current needs for hydrographic and bathymetric surveys and cartographic activities.[19] Satellite geodesy, as has already been explained, is almost unique in providing a means for achieving these. Several oil companies are already investing in satellite-geodesy equipment (Doppler System) to obtain accurate, world-wide ship-positioning capability for their geophysical surveys and drilling platform locations. Satellite geodesy is expected to receive increasing demands for satisfying the needs of the majority of the marine-sciences subobjectives, in particular, those related to effective development of ocean resources.[19,40]

Economics dictates that the development of natural resources must be emphasized in all countries in order to meet future demands of increased population and food shortage. Satellite geodesy, as a tool to improve surveying and mapping capabilities, will definitely play a major role in the future exploitation of natural resources, particularly those in the ocean and other remote areas of the world.[8,10,35,36]

Transportation and Commerce

Contributions of satellite geodesy to transportation and commerce are mostly of a potential and indirect nature involving development of more accurate maps.[45,46] Highway and engineering surveys and construction projects require control points which are now established by routine geodetic techniques; however, satellite-geodesy methods could be profitably applied to the establishment of such control points in the future. The possible contribution of satellite geodesy to transportation on land, in the air, and at sea, is discussed separately under navigation satellites.

Once satellite geodesy techniques are developed to the point where engineering surveys can directly benefit from the location of control points, then they can replace ground-based measurements which are both time-consuming and expensive. Current theoretical studies indicate that satellite geodesy may meet this challenge in the early 1970's.[45]

Agriculture

The contribution of satellite geodesy to agriculture is rather limited. The fiducial-point location subobjective has received the highest relative rating because of its application to detailed map preparation. Other subobjectives are only indirectly related. For example, if sea farming and obtaining food from the sea are to be extended to remote areas, satellite geodesy through marine-science subobjectives could have some application.[19,35,46]

Housing and Community Development

Satellite geodesy could eventually contribute to housing and community development through the establishment of accurate maps for which fiducial-points and control-point subgoals (already discussed) are essential. Satellite geodesy may also find applications in the form of prediction and location of seismically active areas.[8]

Technical Considerations and Forecasts

The most important geodetic subobjectives that will utilize satellite geodesy capabilities and which will extend beyond the 1970's are:

- Marine control points
- Marine geodesy and precise ship positioning
- Oceanography and direct mean sea level determination
- Fiducial points
- Solid-Earth geophysics.

These subobjectives could almost all fall within the satellite-geodesy application objective.

Most of the other existing satellite-geodesy subobjectives, particularly those related to geometric and gravimetric geodesy objectives, most likely will be achieved by the mid-1970's. Few additional satellites of the GEOS or PAGEOS series will be required to complete their mission objectives. Cost estimates for completion of the geometric and gravimetric objectives of satellite geodesy are $50-75 million over a five-year period.[6] However, the 1969 NASA allocation for the total satellite geodesy program is only of the order of $4 million per year.[47]

To date, two basic types of geodetic satellites have been utilized in these studies:

(1) Active satellites, which contain flashing lights, electronic ranging equipment, doppler and laser equipment, are used for all purposes of satellite geodesy.

(2) Passive satellites, such as Echo and PAGEOS (utilizing their reflecting surfaces), are used primarily in geometric geodesy.

Many other nongeodetic satellites, such as Vanguard, Echo, Syncom (communications satellite) have also contributed significantly to satellite geodesy, particularly in achieving some of the gravimetric subobjectives. It can be expected that application satellites of the future may perform combined functions in communications, meteorology, mapping, geodesy, and navigation. Such satellites as the Application Technology Satellites (ATS) are already performing experiments in communication, meteorology, navigation, and other related subjects.[48] The ATS satellites, particularly those at geostationary orbits, will find applications also in geodesy. Limited geodetic studies related to the gravimetric objectives have already been performed.[49] The full potential of these satellites to the geometric and application support objectives is yet to be realized.

Marine Control Points

Several hundred publications treating technical details, requirements, and long-range prospects associated with future geodetic satellite developments and their applications were recently reviewed for a different study. However, the brief discussion which follows is based primarily on references already cited, as well as References 50-69.

For all practical purposes, satellite geodetic methods have the best potential for establishing marine geodetic control points, particularly in the deep ocean. At present, an active type of satellite, primarily one employing a Doppler system, is considered optimum for such control-point establishment. The use of C-band and S-band radars with properly equipped satellites (GEOS type) and similar equipment on board ships also has potential for establishment of Marine control points. Other types of active or passive satellites could also be used to obtain redundancy in measurement and to improve results. Existing satellite technology is well within the state of the art and no breakthroughs are required to undertake such a task. Improvement in measuring ship velocity will be required before any further improvement in the Satellite Doppler system is possible. With satellite radar ranging measurements, ship velocity is not critical. The number of Doppler satellites required on a world-wide basis could vary between three and twenty-four satellites. The time period needed is beyond 1980.

Marine Geodesy and Precise Ship Positioning

Satellite geodesy also has the best potential to satisfy this subobjective. In fact, satellite geodesy appears to be the only means capable of sufficient accuracy on a world-wide basis. Marine geodesy requirements vary, depending on the particular field of application. For example, gravity measurements will require accuracies in position of the order of 50 to 600 feet, while geoidal determinations require accuracy in the vertical coordinates of the order of 3 to 10 feet.

Satellite geodesy technology could meet a ±100 feet accuracy requirement, provided other means are available to eliminate errors in ship velocity. However, geoidal accuracy requirements may not be fulfilled until the mid-1970's. Active satellites are required for Doppler and satellite altimetry. Breakthrough in satellite (laser or microwave electronics) altimetry is possible in the near future. However, fulfillment of marine geodesy subobjectives will extend beyond the 1980's.

Oceanography

Satellite geodesy contributions to oceanography are highlighted by precise ship-positioning capability and direct mean sea level determination (geoid). An accuracy of ±300 to 600 feet in positioning of oceanographic measurement, which is within the state of the art of the Doppler satellite system, could be met. Additional satellites (a total of 24) would be required at all times for continuous positioning on a world-wide basis. Other oceanographic measurements (such as currents, synoptic data collection, telemetry, etc.) require less accuracy and fewer numbers of satellites. These types of satellites are discussed in the chapter on Navigation and Traffic Control.

An accuracy of a few inches (or 10 to 100 centimeters) is required from satellite altimetry for direct determination of mean sea level and would require a technology breakthrough. Such capabilities could not be expected before the mid-1970's or even into the 1980's. Few satellites would be required to satisfy this objective, however, once technical problems are solved.

Fiducial Points

Instantaneous detailed mapping capability is desired on a world-wide basis. Satellites possess the only potential for providing such a real time capability and fiducial-point requirements for 1:25,000 scale mapping could be achieved. However, cost reduction is essential to compete with currently employed aerial methods. An advancement in the state of the art may be required here, as well as a cost reduction. In this regard, cost estimates for four satellites (still in the proposal stage) needed to meet such a requirement suggests that, in the mid-1970's, this approach may be possible. If this is to be achieved, requirements for satellite geodesy will extend into the 1980's and even 1990's.

Solid-Earth Geophysics

Satellite-geodesy) technology associated with distance measurement, gravitational perturbations, and other factors affecting the dynamics of the satellite offer great promise for Earth-science application. However, a breakthrough in satellite technology will be required for satellite geodesy to become more beneficial to solid-Earth geophysics and other related Earth sciences. As in oceanography, satellite-geodesy capability for predicting movement in the Earth structure of the order of a few centimeters over a long period of time is necessary. Such high accuracy is required for the determination of continental drift, Earth tides, convection currents, horizontal and vertical movement, earthquake and tsunami predictions, etc.

An active satellite with altimeter or distance-measuring equipment and other supporting electronic and gravity gradient-measurement instruments is required. Recent developments in satellite interferometry technology show great promise for the solution of these problems, particularly continental drift.

Planned Geodetic Satellites and Associated Launch Vehicles

On the basis of References 2, 70-72, Table X-3 was compiled to show the more recently noted funded, planned, and approved geodetic satellites and associated launch vehicles. The GEOS B satellite, launched in January 1968, is also included in the table because GEOS C, D, and E satellites are expected to have similar on-board equipment.

Since this chapter was written, the Commission on Marine Sciences, Engineering and Resources has presented its final report, "Our Nation and the Sea, A Plan for National Action"[73] to the President. The areas of research recommended and proposed National Goals in Oceanic and Atmospheric sciences that are presented in this report confirm and strengthen the goals and objectives discussed in this chapter.

TABLE X-3. GEODETIC SATELLITE POSSIBILITIES AND ASSOCIATED LAUNCH VEHICLES AND COSTS

Satellite	Scheduled Launch Date	Estimated Cost, ($ Millions)	Payload Size/Weight	Orbital Elements, A/P/L/I	Launch Vehicle	Remarks
GEOS B	January, 1968	Spacecraft:	diameter - 132 cm[70] ht - 81 cm wt - 193 kg (68 kg of instrumentation)	A = 1500 km[70] P = 1100 km L = 18 months I = 74°, prograde	Thrust Augmented Delta[70] (TAD)	• Mission objectives (same as GEOS-A) include connecting geodetic datums to establish one world datum and adjust major datums to the center-of-mass of the earth so that positions of geodetic control stations will have a relative accuracy of ± 10 meters or better in an Earth center-of-mass coordinate systems.[71] • Equipped with optical beacons, C-Band transponders*, passive reflector*, SECOR transponder, GRARR transponder, laser reflectors, laser detector*, beacons.[71]
GEOS C	1970[2]	Spacecraft: 9.9	diameter - 132 cm[61] ht - 81 cm wt - 193 kg (68 kg of instrumentation)	A, P, L: altitude=600 n.mi.[2] (≈ 1112 km) I = 20°	Expected to be a thrust augmented Delta[70]	• Provide additional data required for attainment of NGSP objectives and support a proof-of-concept demonstration and pre-operational validation of a satellite-borne radar altimeter.[2,72] • Also possible to carry an Apollo Unified S-Band transponder.[2]
GEOS D	1972[2]	Spacecraft: 10.3	diameter - 132 cm[70] ht - 81 cm wt - 193 kg (68 kg of instrumentation)	Alt = 600 n.mi., low eccentricity L = 12 months Near-Polar inclination[2]	Expected to be a thrust augmented Delta[70]	• Will support an operational satellite altimeter experiment to support Oceanographic investigations during the International Decade of Oceanography (IDO).[2]

* New on GEOS-B.

TABLE X-3. GEODETIC SATELLITE POSSIBILITIES AND ASSOCIATED LAUNCH VEHICLES AND COSTS (Continued)

Satellite	Scheduled Launch Date	Estimated Cost, ($ Millions)	Payload Size/Weight	Orbital Elements, A/P/L/I	Launch Vehicle	Remarks
GEOS E	--	--	diameter = 132 cm ht = 81 cm wt = 170 kg (55 kg of instrumentation)[70]	--	Expected to be a thrust augmented Delta[70]	--
AAGS-A	--	--	diameter = 140 cm ht = 120 cm wt = 220 kg[2] (120 kg instrumentation)	L(estim.) 24 months Alt.(estim.) = 500 km[61]	--	• Precision spacecraft altitude stabilization and measurement techniques required to provide accurate orientation of satellite altimeters and of sensors for earth-science support.[70] • Spacecraft contain beacons, transponders and passive reflectors to enable very accurate position measurements to be made by ground observation stations and by oceanographic ships for ship positioning.[70]
AAGS-B	--	--	diameter = 140 cm ht = 120 cm[2] wt = 220 kg (120 kg instrumentation)	L(estim.) 24 months Alt. (estim.) = 500 km[70]	--	• Mission objectives include refining accuracy of fiducial points on the earth surface up to 10 centimeters accuracy and providing densification of geodetic control points on the earth surface up to one meter accuracy.[70]
AAGS-C	--	--	diameter = 140 cm ht = 120 cm wt = 220 kg[2] (120 kg instrumentation)	L(estim.) 24 months Alt. (estim.) = 500 km[70]	--	

* New on GEOS-B

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CHAPTER XI. NAVIGATION AND TRAFFIC CONTROL SATELLITES

GOAL: To develop space technology to provide mobile vehicles or platforms with improved position information, communication and traffic control leading to better travel safety, data collection and telemetry, and search and rescue aids

RELATION OF NAVIGATION AND TRAFFIC CONTROL SATELLITES TO NATIONAL GOALS:

	NATIONAL (FUNCTIONAL) GOALS												
PROGRAM OBJECTIVE AREAS	EDUCATION & KNOWLEDGE	SPACE	NATIONAL SECURITY	VETERANS	LABOR & MANPOWER	WELFARE	HEALTH	COMMERCE, TRANSPORTATION, & COMMUNICATIONS	GENERAL GOVERNMENT	AGRICULTURE	NATURAL RESOURCES & ENVIRONMENT	HOUSING & COMMUNITY DEVELOPMENT	INTERNATIONAL RELATIONS
AIR NAVIGATION	●	●	●					●		●	●		●
SEA NAVIGATION	●	●	●					●		●	●		●
LAND NAVIGATION	●	●	●					●		●	●		●

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CHAPTER XI

NAVIGATION AND TRAFFIC CONTROL SATELLITES

A. G. Mourad and J. H. Holdahl

Introduction

A Joint Navigation Satellite Committee (JNSC) consisting of six government agencies (Departments of Commerce, Defense, Interior and Treasury, Federal Aviation Agency, and NASA) was established in September, 1964 and functioned to 1966, studying the use of nonmilitary navigation satellites for improved air and sea navigation, traffic control and rescue operations, and related functions.[1-3*] The Committee considered several factors including techniques, accuracy requirements, economic feasibility and benefits, and cost-effectiveness.[2] The accuracy criteria considered ranged from location determination of ±0.05 n. m. for special marine use to ±3 n. m. for general navigation. The Committee's report stated that "space technology and economic considerations are sufficiently promising to warrant continued determined investigation of the technical and economic feasibility of utilizing satellites for the purposes considered by the JNSC, either separately or in combination with non-satellite techniques".[4]

The Space Application Summer Study of the National Academy of Sciences also identified many possible uses for navigation satellites in air, sea, land, and space programs.[5] Many other technical reports and papers indicate the potential of a worldwide satellite navigation system with emphasis on air navigation and traffic control.[3,6]

NASA has undertaken several other studies since the completion of the JNSC work to explore possibilities for implementing the recommendations of the Committee. One of these, the Navigation and Traffic Control (NTC) Program, was of special interest during the study reported here which was aimed at relating satellite navigation and traffic control requirements and potential benefits to national goals.

Goals and Objectives

The goals and objectives of NASA's satellite NTC Program have been stated differently in several references.[1,7-10] In some instances the goal is stated as determining the utility of satellites for serving the aviation and maritime community, in others, as assisting in the improvement of air and sea travel, etc. The most representative goal statement derived from these various sources is developing space technology to provide mobile crafts or platforms with improved position information, communication and traffic control. These would make possible improved travel safety, data collection and telemetry, and search and rescue aids.

The broad objectives of the NTC program relate to providing:

(1) Position-fix information for air, sea, and land

(2) Traffic control and safety of navigation through

   (a) Position determination

   (b) Communication service

   (c) Telemetry service.

* Superscripts denote references cited at the end of this chapter.

Three specific functional objective areas have been identified for the program reported here:

(1) Air navigation

(a) Position determination

(b) Traffic control

(c) Search and rescue

(2) Sea Navigation

(a) Position determination

(b) Traffic control

(c) Search and rescue

(d) Data collection/telemetry

(3) Land Navigation

(a) Position determination

(b) Traffic control.

General Considerations

The global coverage, singularity of system, accuracy, and versatility of satellites offer several attractive possibilities for navigation and for traffic control. Satellite navigation functions can be accomplished in many ways. These functions are affected by many factors, including the type of measuring systems used, selected satellite orbit characteristics, and purpose.

Obviously, different uses are likely to create conflicting requirements, as to accuracy and cost, for example. In addition, there are many geopolitical factors that at present seem to override technical and economic considerations. The characteristics of an overall navigation satellite system must be based on many tradeoff possibilities.[3] It is anticipated, however, that eventually a worldwide satellite navigation system will be utilized, at least for air and marine purposes, and that this will make it feasible to improve traffic control and search and rescue operations for air and marine emergencies.[11]

Before the broad objectives of NASA's NTC program are considered, it is important to understand the type and capabilities of the basic measuring techniques that would be involved in a satellite NTC system and the importance of selecting a suitable satellite orbit.

Measuring Techniques. Four major categories of measuring techniques are used in navigation to determine the position of a craft or an observer:[12]

(1) Distance (range) measurement

(2) Rate of change of distance measurement

(3) Angle measurement

(4) Rate of change of angle measurement.

The last, while theoretically possible, is not considered suitable for an operational system.

Three basic approaches have been generally considered for a universal satellite navigation system usable by air, sea, and land crafts: (1) use of distance or distance-difference data, (2) use of distance and angle-measurement data[12], and (3) use of rate of change of distance data (Doppler system).[14]

Distance Measurement. The most direct method of measuring distance or distance difference is in terms of the propagation time of the signals between a satellite and an observer. Measurement can be made at the mobile craft, at the satellite, or at the ground station. There are several possible approaches for position determination using satellite distance measurement. For example, one approach involves the measurment of two ranges simultaneously to two satellites (or three to three satellites if altitude is not known). The intersection of three spherical surfaces determines the position fix. This is advantageous because well-known measurement techniques can be used. However, the error of the position fix is magnified as the angle of intersection of the three surfaces becomes more acute. When aircraft are under consideration this is combined with the difficulty of measuring aircraft altitude at cruising levels.[15]

Another approach involves the measurement of two or three ranges to one satellite at different times. This requires accurate knowledge of the craft's motion, however, because position errors are large if craft motion is unknown. Such a system would not be practical for aircraft.

Another approach involves the use of a transponder on the mobile craft activated by a signal from a ground station and relayed by the satellite.[7] The ground station activates all users. The distance is measured from the difference between direct and delayed repeat-back. A system consisting of 16 to 24 satellites in four high-inclination orbits at altitudes of 700 to 1,000 kilometers and six ground stations are needed for worldwide coverage. However, two satellites in synchronous orbits at 36,000 kilometers would cover the Atlantic Ocean.

For distance-difference measurement, the observer must be able to see simultaneously two (with knowledge of altitude) or three satellites. The distance measurement is made by phase-difference techniques, the intersection of hyperbolic surfaces determining the position fix. Experimental programs have been and are being conducted on these systems. In range-difference techniques one additional satellite in synchronous orbit for each case mentioned above is required.

Measurement of Distance Rate of Change. The observer's position can be determined with respect to the satellite by measurement of radiating pulses or a continuous wave from the satellite.[12] Time intervals between successive pulses are measured on the mobile craft. Another technique involves the measurement of the Doppler frequency shift of a continuous wave transmission of two stable frequencies from the satellite. The plotted curve of the Doppler effect is a function of the distance rate of change and can be differentiated for the slant range of the satellite. The user compares the frequency of signals from a satellite with a frequency standard aboard his craft for a period of several minutes noting the Doppler frequency shift. Satellite orbital parameters are kept up to date through a tracking network. The user computes his position. From Doppler observation, the instant of closest approach to the observer and the minimum slant range can be deduced. Twenty-four satellites in near-polar and circular orbits are required for continuous coverage. The Doppler satellite navigation system is the only operational system in use for ship positioning. This system, while ideal for ship navigation, is not as suitable for aircraft because the high speed of the aircraft reduces its accuracy.[16] Other studies indicate that the Doppler system has potential for aircraft position determination.[14] However, for navigation and traffic control, voice communications and surveillance are required, for which the Doppler navigation system has no capability. Furthermore, the Doppler system is not suitable for navigation satellites at synchronous altitudes.[16]

Angle Measurement. Angle measurements can be made either at the user craft or at the satellite. At the satellite, directional antennas or interferometers are required to receive the signals transmitted by the user craft and to measure angles. The information is then transmitted to the user.[12] A variation is to have the satellite transmit signals from a directional antenna, phased array, or interferometer to the user who computes his position with relatively simple equipment. This is suitable for multi-user purposes. However, several ground stations are required to position and update (interrogate) the satellite, which may limit the accuracy of system as a universal operational system. At synchronous altitude, an interferometer base line of 100 wavelengths is considered adequate for measurement of angle.[12] Frequencies of 800 to 8,000 MHz are utilized. Eight satellites at 7,000 to 10,000 kilometers altitude and with high-inclination orbit would give worldwide coverage. One satellite at synchronous orbit could cover the Atlantic Ocean between the latitudes 70 degrees S and 70 degrees N.

Precise angular measurements have been made on the ground but have not yet been demonstrated in space. Interferometers show potential for accomplishing this, however.[15] The use of an interferometer has the advantage that a single suitably equipped satellite can provide the needed information for a position fix.[7] Angle measurements can be made as follows:[17]

(1) Direction pulse is received at the satellite by two sets of interferometers at right angles to each other

(2) Phase difference measurement is made on the wavefront arriving at the elements of the interferometer and are relayed as range differences to the user. The interferometer is then a hyperbolic system with a baseline small enough to allow simple interpretation of measurements in terms of angles.

A disadvantage is that radio interferometer antennas requiring booms approaching hundreds of feet long must be placed into space and this is more difficult than to use radar ranging techniques requiring space transponders.[7] Angular ambiguity can be resolved by transmitting on a second frequency slightly removed from the first and by a computational process.[15]

Combined Measurement of Angle and Distance. The procedure for measurement of angle and distance is similar to range difference measurement (which require simultaneous measurements of the distances between the user and two satellites) except that one distance and two angle measurements from the satellites are made. Five radio-frequency channels are required. The advantage is that the three surfaces which determine the position fix intersect at nearly right angles and hence accuracy is independent of the relative position of the craft with respect to the satellite.[15,18]

Westinghouse's proposed system of measuring one distance and two angles involves the location of the satellite itself with respect to the geoid as the fundamental point for all position calculations.[15] This is accomplished by substitution of ground reference stations at known locations for crafts in the measurement cycle. Inputs for position computation are satellite location, interferometer altitude and spacing, phase measurement of interferometer, and distance from satellite to craft. Computations could be performed in a fraction of a second by electronic computers and automatically displayed on each craft within a second after measurement.

<u>Orbits for Navigation Satellite Systems</u>. Knowledge of a satellite's position in its orbit is required at least 24 hours or more ahead for the use of navigation satellites. Suitable orbits are above 300 kilometers because of the effect of the atmosphere. The choices of satellite orbit and number of satellites depend on the type of service, availability, coverage, and accuracy required. For ship use, one satellite is sufficient (Doppler). Additional satellites would provide more fixed interval navigation.

Synchronous orbits are not suitable for Doppler use. For airborne use, Doppler is not sufficient and continuous navigation (more intervals) is required. For synchronous orbits, altitude stabilization and orbit corrections are required, particulary for angle measurement and for transmission to the satellite. The major considerations for satellite orbit selection for a navigation satellite system are as follows:

(1) The geometry of measurement from the user craft to the satellite. Most systems under consideration are based on making range and/or range difference measurements rather than angle measurements.

(2) Accurate tracking and determination of satellite orbit. In general, the orbit of a stationary satellite is the more difficult to determine.

One system design considered involves using satellites at synchronous altitude but in elliptical and slightly inclined orbits. Three elliptical satellites at 30 degrees inclination tracing a circle on the Earth's surface would be required with a stationary satellite at the center of the circle.[19]

Satellite NTC Program Objectives

The Satellite NTC program goals and objectives were earlier related to providing two general classes of service:

(1) Position-fix information for air, sea, and land

(2) Traffic control and safety information.

Three functional objective areas were identified as being significant for the study reported here:

(1) Air Navigation

(2) Sea Navigation

(3) Land Navigation.

Following are discussions of the problems and objectives of all three, and, as appropriate, solutions that could be provided by a satellite navigation system.

Air Navigation. A multitude of functions must be served by aircraft including position fix, traffic control, collision avoidance, search and rescue, passenger-telephone, entertainment, weather advisory, solar event advisory, and border control processing. In most cases reliance is on some kind of position fixing information; in the case of collision avoidance, on fast, precise position fixing and quick-reaction ground control. In the rest, reliance is on communication.[11,20]

Satellite technology has potential for providing aircraft with aids to enroute navigation, information for collision avoidance, and search and rescue data, and weather advisories on a worldwide basis.[11,20] General agreement has been achieved on the basic type of satellite system that could and should be implemented. Some of the following system characteristics have been identified:[11,18]

(1) All-user and all-area operation provided by multiple, synchronous quasi-stationary satellites with most of the necessary signals for navigation being transmitted by satellites to all users

(2) Relatively simple satellites, multichannel, multiband, communication repeaters

(3) Ground tracking station in control with an accurate multifrequency satellite ranging subsystem for determining the relative location of each satellite within its purview to ±90 feet at all times

(4) High performance and reliability (combining navigation, communication, and intelligence)

(5) Low cost.

The services provided by an ideal system would pertain to position determination, traffic control and separation standards, and search and rescue operations.

Position Determination. The measurement of the position of the mobile craft with respect to a reference system or relative to another craft at a given time is called a position fix. Measurement of the relative positions of several aircraft within a given air space must be made using a single and universal system to avoid errors likely to cause collisions. Aircraft can obtain a position fix from satellites by

(1) Measurement of the ranging from the aircraft to two satellites. The aircraft transmits and measures the time to receipt of reply.

(2) Measurement of range difference to three satellites.

Neither is ideal for continuous guidance.

Each class of aircraft imposes its own requirements for position determination:

(1) <u>Subsonic aircraft</u> - Frequency of position fix required has been reported to be one position fix every 5 to 8 minutes.[21,22] Accuracies of ±5 to ±10 n. m. standard deviation as reported by the International Civil Aeronautics Organization (ICAO) is the future requirement.[23]

(2) <u>Supersonic Transport (SST)</u> - Frequency of position fix varies from nearly continuous to every 4 minutes.[8,13,21,35] Accuracy of ±5 to ±10 n. m. is required; in addition, highly accurate altitude and heading data are vital.[23]

(3) <u>Advanced Supersonic Transport (ASST)</u> - Frequency of fix is needed every 16 seconds.[24] Accuracy of ±1 n. m. (one sigma) is a design goal for NASA/ERC studies for satellite navigation.[24]

(4) <u>Specialized Aircraft</u> - Certain specialized aircraft such as ice-patrol craft require a position fix accuracy of ±1/2 n.m. or better at 10-minute intervals.[8]

The ideal positioning system would have[13]

(1) An attainable position accuracy of 1 n. m. with a growth potential of 0.1 n. m. or better

(2) Hardware failure not to exceed 5 to 10 minutes

(3) Nearly continuous position fixing capability so that additional useful information related to average velocity determination and traffic control is obtainable.

Traffic Control. In air traffic control, emphasis is being placed on the ability to follow a preselected path and to maintain a scheduled position at high traffic volumes without danger of collision and with maximum economy of operation.[25] This means that the ground controller must know the location of all aircraft and must have a reliable means of relaying instructions.[25]

The present system of air traffic control in the North Atlantic, although not yet overloaded except during peak periods[7], will reach the saturation point within the next few years. The national ATC system handled 41 million takeoffs and landings in 1966 and this is expected to grow to an annual rate of 139 million in the next decade.[26] By 1975, 900 flights per day during peak season are predicted in the North Atlantic.[27] Therefore, about 278 aircraft could be in the air simultaneously in this area.

Satellite air traffic control objectives are as follows:

(1) Improved communication by developing

(a) Technology that permits communication in a noisy environment to aircraft with low-gain antennas

(b) Multiplexing techniques that allow many controllers, aircraft, and ships to communicate through a satellite with minimum waiting periods. Experiments are being performed on ATS-I and ATS-III and will continue on additional ATS satellites and Nimbus.[7]

(2) Improved or reduced aircraft spacing which will necessitate accurate position determination.

The application of space technology could help especially in those parts of the world where conventional aeronautical ground stations employ HF or VHF channels and would be unable to provide the required coverage and level of communications reliability at all times, particularly in the North Atlantic.[6] Over ocean areas and sparsely populated areas of the world, aviation is forced to rely on HF radio communications, which depend on ionospheric reflection for desired coverage. The ionosphere does not always behave in a desired way and even when an aircraft has a number of high-frequency channels to select from, communication may either be impossible or so distorted as to create potentially dangerous situations.[6]

Without an adequate ATC system the only means to ensure collision avoidance is to separate aircraft widely in altitudes, tracks, and times of departure.[28] Collision prevention devices are not acceptable substitutes for a safe and efficient control system; rather, they should be considered as redundant.[25]

The all-weather capability of satellite navigation systems and the predictable fixing accuracy are such that when all aircraft are equipped, lateral separation in the North Atlantic can be reduced. Interrogration and responses for navigational fixing can be monitored within the computer at the ground-based satellite tracking station, providing the ability to monitor lateral separations and maintain collision avoidance service.[11]

An overall system concept for a Position Location and Aircraft Communication Equipment (PLACE) has been developed.[7] The purpose of the PLACE experiment is, ultimately, to provide two-way voice and digital data communications between aircraft and ground control centers via geostationary satellites to commercial aircraft and air traffic control. Participating aircraft will be equipped with a high-gain L-band antenna to receive ground control voice and data transmission.

Separation Standards. Aircraft separation standards relate to the air corridors assigned to each aircraft for flights to any given destination. These are assigned for safety purpose, to avoid collisions and to permit effective scheduling.[29-32] Present separation standards are large because communication systems are unreliable and navigation systems are inaccurate. Six or more independent tracks will be required to handle the expected volume of traffic across the North Atlantic by the mid-1970's unless the required longitudinal separation between aircraft on the same track can be reduced much below 10 minutes.[31] Separation standard effectiveness depends on the ability of aircraft to keep to assigned tracks. Evenutally, lateral standards will have to be reduced to 30 n. m. or 60 n. m. for economic reasons. Table XI-1 shows probable future lateral separation requirements.

TABLE XI-1. PROBABLE FUTURE LATERAL SEPARATION REQUIREMENTS

Year	Lateral Separation, n. m.	Reference
1965	150	27
1966-67	120	29
1968	90	16,29,31
1975	30-60	29,31
1985	30	5,31
2000	15	29

There is only one optimal transatlantic track between two specific points from economical standpoint, and any deviation from this, increases operating costs. Each 120 n. m. displacement north or south of that track results in an added expense of $200 for each flight.[20] The limitations on the number of aircraft allowed in the air at one time in a given area and time delays in terminal areas also increase operating costs. Delays in the terminal area where aircraft are held in the air at a low level also increase operating costs. The cost penalty with SST's for this type of delay will be about three times that with subsonic aircraft.[31]

Table XI-2, which is based on predicted traffic situation in 1975, illustrates the dollar advantages obtained from the reduction of the lateral standard from 90 to 60 n. m. Results are given for both sonic-boon-restricted and unrestricted systems. Zero delay relates to that method of distributing aircraft among tracks by which the best vacant track available is allocated to an aircraft as it approaches the entry to the system without giving the option of waiting until a better track becomes available. Delayed transition provides the option of delaying an entry until a better track is available. This would greatly benefit SST's although simulation studies show this would not be true for subsonic planes.[31]

TABLE XI-2. GAIN FROM REDUCTION OF LATERAL STANDARD FROM 90 TO 60 N. M.[(a)31]

Sonic Boom Overland	Method of Allocation of Aircraft	Saving in Reduced Operating Cost Per Aircraft	Per Annum
Unrestricted	Zero Delay	\$40(0.3% fare)	\$2,300,000
	Delayed Transition	\$9(0.06% fare)	550,000
Prohibited	Zero Delay	\$740(5% fare)	\$42,000,000
	Delayed Transition	\$46(0.4% fare)	2,600,000

(a) Based on anticipated 1975 traffic situation.

(Reference 31: Attwooll, V. W., "Separation Criteria for Supersonic Transports and Other Aspects", Navigation: Journal of the Institute of Navigation, Summer, 1968, Vol. 15, No. 2, pp 199-204. Reprinted by permission of the Institute of Navigation.)

Results of another study related to separation standards for SST's illustrate the distance and cost penalty for several lateral separations. As lateral separations are reduced, the optimum channel configuration involves fewer vertical channels.[29] Penalties for displacement from the optimum flight path in the vertical channel greatly exceed those due to displacement in the horizontal plane for SST (Concord).[31] Figure XI-1 shows in graphical form the average distance penalty in nautical miles per airplane trip and the average cost penalty in dollars for lateral separations of 120, 60, 30, and 15 n. m. for cruise climb operations of up to 24 airlanes.[29] For example, when 15 channels are considered, the average penalty per airplane per trip for 120 n. m. separations (the present standard) is 480 n. m. distance and \$1,200. For 60 n. m. separations this would be reduced to 160 n. m. and \$400.[29]

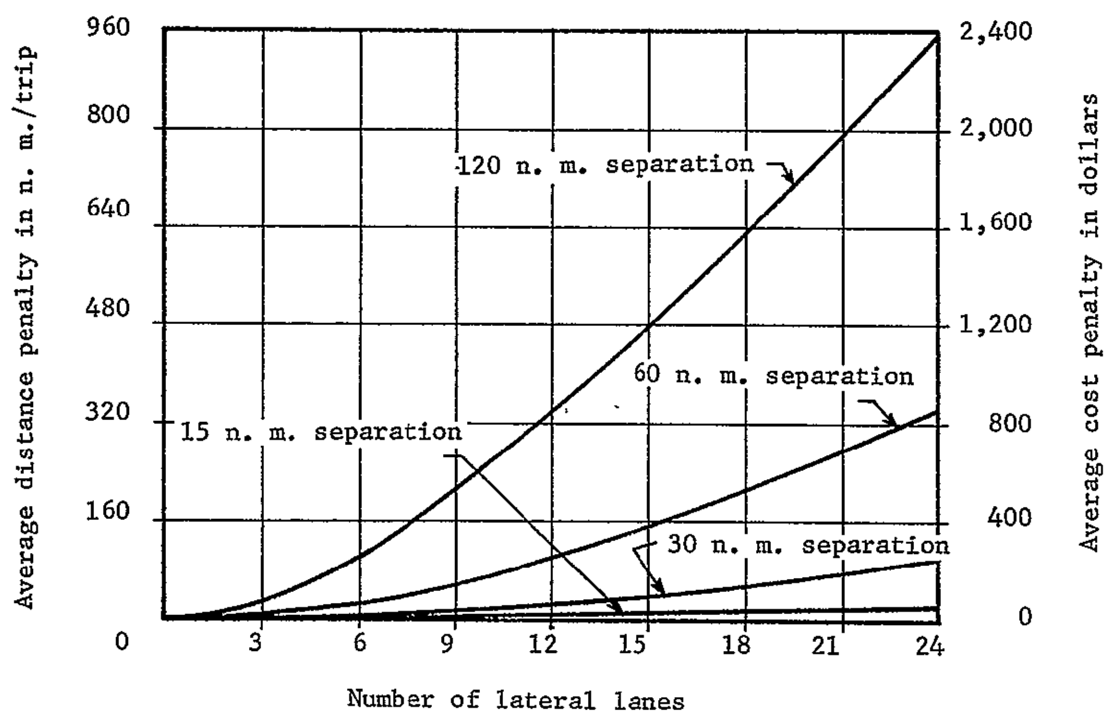

FIGURE XI-1. COST PENALTY DUE TO SEPARATION STANDARDS[29]

(Reference 29: Manis, D., "SST Navigation", Navigation: Journal of the Institute of Navigation, Summer, 1968, Vol. 15, No. 2, pp 175-187. Reprinted by permission of the Institute of Navigation.)

Search and Rescue Operations. A satellite navigation system must have the ability to activate search and rescue operations immediately and to permit organization of emergency procedures from a central location. Such a satellite system would also make possible improved emergency cooperation with ships.[11,33] Search and rescue operations would also benefit from the ability to position downed aircraft immediately. The position could then be relayed at once to aircraft and ships in the area. It would also be advantageous to have continuous position information available on a worldwide basis. In the case of fixed-interval positioning, pilots could be provided with equipment to be operated when they are in distress by "pushing a button" to override the position determination within a fraction of a second and to alarm central control. Sensors could also be added to actuate the equipment in case of fire or shock. If neither the pilot nor the automatic sensors could actuate the equipment, failure of the equipment to transpond at the next fixed-interval interrogation could serve as emergency alert.[33]

Sea Navigation. The capability of satellite technology has already been demonstrated for providing ships and submarines, anywhere in the oceans, with precise position information through the operational Navy Doppler satellite navigation system. However, this system, while good for ship positioning purposes, is not suitable for ship communication, traffic control and data relay, the functions considered important for a single universal navigation system for all users.

The problem of navigation and traffic control at sea is not as complex as problems relative to air navigation, primarily because of the lower speed of ships. However, with the introduction of hydrofoil speed boats which can travel up to 100 n. m. per hour, continuous navigation information and traffic control services eventually will be required. Up to now, most marine navigation needs have been associated with the positioning requirements which, in turn, are presumably satisfied by conventional means and Doppler satellites. Additional Doppler satellites will be needed for supplying near-continuous position information. The cost of satellite Doppler receivers and the computer equipment needed on board ships limits use by commercial ships. Therefore, the main justification for development of a new satellite navigation and traffic control system must be based on air navigation requirements and future requirements for marine traffic control and search and rescue operations. Reduction of equipment cost will also serve to justify such development.

Six marine uses of navigation satellites have been described.[3] These are (1) enroute navigation, (2) commercial fishing, (3) navigational aids to small pleasure craft on the high seas, (4) unmanned sensors, (5) oceanographic research, hydrographic surveying, and offshore resources exploration, and (6) traffic control.

Position Determination. The principle of position determination for ships is similar to that for aircraft which has already been discussed. Position determination in marine navigation is of interest for the location of ships and for data collection and relay from fixed or free-floating buoys and balloons or other platforms. Of interest is the experimental navigation system involved in the Omega Position Location Experiment (OPLE). The purpose of this experiment is to provide position determination and data transfer. The plan is that VLF signals transmitted from the Navy's Omega Navigation System and received by ships, aircraft, or fixed sites will be converted to VHF and relayed through a geostationary satellite to ground stations where position calculations will be made. Preliminary tests on ATS satellites indicate the feasibility of OPLE.[1,7,34]

Position determination requirements vary with different types of ships.

(1) Commercial ships - Frequency of position fix information is automated on a worldwide basis. Accuracy of ±1 n. m. to 2 n. m. is possible with very low cost equipment.[8,35,36]

(2) Search and rescue ships - Frequency of position fix is every 10 minutes to continuous.[3,8,36] Accuracy of position determination required is ±1 n. m.[8]

(3) Ice-breaking ships - Frequency of position fix is every hour with an accuracy of ±2 n. m.[8]

(4) Survey and research ships - Frequency of position fix varies from near continuous to every 10 minutes with an accuracy better than 0.1 n. m. approaching 0.05 n. m.[2,21,36,37,38]

(5) Ground-effect machines, boats, and automated ships - Position fix is required every hour to near continuous with high precision.[3,21,39]

Traffic Control. The equivalent of an air traffic controller does not exist today in marine navigation.[39] Over the years, no restrictions have been placed on sea routes or lanes for ships as with the air corridors for aircraft. The slow speed of ships (less than 1 n. m./hr) gives the ship's captain enough time to react and take necessary steps to avoid collision with other ships crossing his track. Increased ship traffic and efforts to achieve economic operation through selection of optimum courses for all ships may cause more accidents in the future. During 1967, 1,500 commercial vessels and about 5,274 recreational boats were involved in collisions and accidents in U.S. waters that caused 1,452 fatalities.[40] Need for traffic control and assignment of sea lanes analogous to air lanes is becoming more evident.

A marine traffic control agency with a central control station on shore to coordinate traffic on ship routes over all the oceans has been recognized. However, up to now, it has not been feasible to establish such an agency because of the lack of navigational accuracy and reliable voice communication systems for use between controller and ships. Satellites could provide both.[3] The technical requirements include position accuracy of ±0.05 n. m., a reliable voice communication channel, and worldwide coverage. Geopolitical factors involved are more difficult to assess.[3] The primary value of a traffic control agency would be safety of navigation.

Search and Rescue Operations. When accidents occur at sea, whether to marine, air or space vehicles, search and rescue operations must begin immediately. If the position of the vehicle is known at the time of accident, rescue vehicles can be dispatched to the scene immediately. The coordination of the search operations is also of prime importance. Navigation satellites have advantages in that, with one system, they can permit shore-based search and rescue stations to determine the position of a distressed vehicle within 1 n. m.[8], dispatch rescue crafts, communicate with those involved, and coordinate air and sea search.[2,3,39]

The basic requirements for ships involved in search and rescue operations are the same as for aircraft. In addition, some ships are involved in underwater search operations for which, in addition to a satellite navigation system, an acoustic navigation system is also required.

A shore-based ground station, working through a pair of satellites, could determine the position of a ship and cause it to be displayed immediately on the ship's equipment and to be recorded ashore for use in the event of an emergency. Similar capability is also available for home office use for such functions as remote navigation of automated ships.

Data Collection and Telemetry. Another main concern is data collection from remote areas and from sensors on buoys, balloons, or isolated fixed platforms. Satellite navigation requirements would be for positioning and tracking these vehicles in real-time, interrogating them and receiving their data, and telemetering or relaying them to a ground control or to a coordinating center. Examples of such systems are OPLE (already discussed) and the interrogation, recording, and location experiment (IRLS) used with the Nimbus spacecraft. Prime interest for the latter experiment is collection of meteorological data, such as temperature, pressure, wind and humidity, sea state, and ice.[1]

Land Navigation. For most land-vehicles, position determination by satellite is not required. Most navigation requirements are satisfied by other means. However, there is some need for use of satellite navigation systems, particularly in remote areas such as the Arctic and in conflict areas such as Vietnam. In such cases, satellites might be the only means of providing the necessary position information. There is also a quickly developing need for accurate position information and traffic control for high-speed trains.[39] Some trains are expected to travel at about 200 miles per hour.

Automobile, bus, and truck transportation already creates a ground traffic control problem during peak traffic hours. Present control methods involving use of helicopters and low-speed aircraft provide some local service. Effective satellite technology might be developed, perhaps involving use of photographic sensors if sufficient resolution can be obtained.

Relation to National Goals

Table XI-3 presents a numerical estimate of the relevancy of navigation and traffic-control satellite program areas and objectives to national goals. The national goals associated with navigation problems are as follows:

- National Security
- Commerce, Transportation, and Communications
- Education and Knowledge
- International Relations
- Natural Resources and Environment
- Space
- Agriculture.

Commerce, Transportation, and Communications

It would be expected that satellite navigation and traffic control programs would have direct relevance to Commerce, Transportation, and Communications because business and commerce prosper with the existence of an effective transportation system. For transportation safety, accurate positioning and navigation data and effective communications are required. A satellite navigation and traffic control system could fulfill these requirements. The largest class of users by far of such satellite system will be general aviation and small craft operations.[16]

Moreover, commerce has a global role. For example, except for certain Communist Block countries, the U.S. conducts trade with most of the world, and U.S. interests have established businesses in many countries. Transportation of cargo and people to and from these countries, whether for business or pleasure, involves travel by land, sea, and air. Air travel and transport is increasing at a tremendous pace and by the mid-1970's, navigation accuracy requirements because of the density of supersonic and advanced supersonic aircrafts, particularly across the North Atlantic, will not be met unless an operational navigation satellite system has been developed. A need, therefore, exists for a universal navigation and position determination for the vehicles involved in such transportation.

The Maritime Administration estimates that yearly benefits achievable by 1975 using automatic satellite-derived navigation information could be between \$600,000 and \$1,400,000 for all U.S. ships.[21]

TABLE XI-3. ESTIMATE OF RELEVANCY OF NAVIGATION AND TRAFFIC CONTROL SATELLITES TO NATIONAL GOALS

Program Objective Areas	Specific Objective Areas	National (Functional) Goals: National Security	Commerce, Transportation, & Communications	Education & Knowledge	International Relations	Natural Resources & Environment	Space	Agriculture
Air Navigation	Position Determination	3	4	3	3	3	3	1
	Traffic Control	3	5	3	3	2	3	0
	Search and Rescue	4	5	2	3	2	4	0
	Data Collection/ Telemetry	3	4	2	3	3	2	1
Sea Navigation	Position Determination	3	3	2	3	4	4	2
	Traffic Control	2	4	1	3	2	3	0
	Search and Rescue	4	5	1	5	1	5	0
	Data Collection/ Telemetry	3	4	3	3	4	3	3
Land Navigation	Position Determination	3	2	1	1	3	1	1
	Traffic Control	2	3	1	1	1	1	1

Relevancy:
- 5 Critically relevant
- 4 Fundamentally relevant
- 3 Advantageously relevant
- 2 Conveniently relevant
- 1 Remotely relevant
- 0 No apparent relevancy

A navigation satellite system could offer not only the position determination capability required for the future but also a traffic control capability which is of the greatest importance for commerce, transportation, and communications, particularly to ensure the safety of passengers and cargo. For safety purposes, the Federal Aviation Agency has established a VHF omnidirectional radio-range system for air navigation over the continental U.S. at a cost of $300 million over a 10-year period.[5] The cost of implementing a satellite navigation and traffic control system of worldwide coverage has been estimated also at $300 million over a 10-year period, including both initial investment and yearly operations.[5]

One cannot evaluate safety in terms of economic returns, particularly when human lives are involved. Traffic control capability with the control center able to track, monitor, and communicate with all aircraft for such purposes as collision avoidance and relaying of weather information and telephone messages can be provided only through a satellite navigation system. In addition to the safety aspects, the Space Applications Summer Study estimated that direct economic benefits of about $50 million could be expected from implementing an operational global NTC system.[5]

Search and rescue operations are among the most important commerce and transportation activities, particularly when they involve lives. An effective satellite navigation and traffic control system that can locate emergencies, dispatch search and rescue vehicles from the nearest station, and maintain an effective search pattern would definitely increase the speed and success of such operations.

Savings in operational costs of about one-half million dollars can be anticipated with a satellite NTC system for each major incident involving sea searches for downed aircraft or overdue ships.[21] It is desirable to have low cost ship equipment for receiving satellite-obtained information from a shore station and displaying it immediately on shipboard equipment. Total cost of ship equipment required is estimated at $2,000, including readout display.[36]

Additional potential benefits from a navigation and traffic control satellite system would be derived from the ability to select optimum routes for aircraft; this would lead to direct economic advantages. Air transportation has become an essential catalyst to American business.[41] Costs involved in flight delays due to air traffic congestion alone have many effects. One such effect is directly related to the airlines resulting in increased operational costs, fuels, rescheduling, perdiems, etc. The other costs are perhaps indirect in that they involve the traveler who may miss connections and is forced to stay over which naturally reduces the efficiency of business by increasing overall cost and reducing business profit.

The ability to utilize satellites for collecting marine geophysical and meteorological data from buoys, platforms, and balloons in remote ocean areas and for relaying these data to control centers on land is another possibility.

All potential benefits mentioned above would also apply at sea, although, the sea traffic control problem is not yet critical. However, the possibility for coordination of search and rescue operations to aid aircraft or sea vehicles in trouble at sea by a central control makes a satellite navigation system attractive.

Space

The U.S. Navy pioneered in the development, in the early 1960's, of the world's first operational Doppler satellite navigation system for military uses. Recently, since 1967, this system has been in use by both the military and civilian agencies. NASA has a formal program aimed at application of space technolgy to the development of a satellite navigation system for peaceful uses that can meet air and sea navigation requirements. So far, this program has been limited to the execution of a few satellite navigation experiments. The development of specific satellites for navigation purposes is still in the planning stage.

NASA's NTC program is expected to be first to develop and apply a worldwide satellite navigation system, thus maintaining the planned U.S. role as a leader in space activities in general and space applications specifically. In addition, making NTC information available to other nations, particularly smaller and underdeveloped countries that do not have the capability nor the resources for developing their own useful navigation system, is well within the scope of the national space goals. Table XI-3 indicates that extent to which NASA's satellite navigation and traffic control program may contribute to national space goals and objectives. For example, with respect to air navigation,the relevancy ratings vary from advantageous to fundamental importance.

The relevancy ratings for sea navigation range from advantageous to critically important. There is one critically relevant rating associated with search and rescue operations. Many sea navigation requirements are currently being fulfilled through the use of systems other than NASA satellites. The low relevancy ratings for land navigation indicate that these requirements are being met with other systems.

NASA's NTC program contributes directly to the space program, particularly in search, rescue, and recovery operations of the astronauts and spacecraft. U.S. space recovery operations could derive direct benefits from an effective satellite NTC system in coordination of air and sea activities. Moreover, an NTC program would contribute significantly to accurate position determination of tracking ships and Range instrumented ships. These ships, which are equipped with the most complex and sophisticated tracking and computing equipment, serve a major role in spacecraft trajectory determination.[38,42] Real-time information on ship or tracking platform positions over the world's oceans during space missions can only be obtained through a satellite navigation system.

International Relations

If NASA's NTC satellite program is to provide a truly worldwide navigation system, appropriate international agreements must be reached. Therefore, an NTC satellite system is, in concept, an international system. However, because of political reasons it may not become totally operational for years to come. International agreements are required particularly to settle problems of frequency allocations and cost sharing. In any case, NTC program objectives and the application of results for peaceful purposes could have important effects on bringing various countries closer together. The main problems to be overcome are political, not technological.[3]

Some of the smaller nations and pro-U.S. nations would benefit from NTC application on an international scale and perhaps they will favor a universal system from an economic point of view or because of loyalty. Conversely, other nations, because of national pride or international competition, might be against development of such a system. Of maximum benefit to all nations would be a universal traffic control system with all vehicles being controlled by one or a few centers.

Search and rescue operations have many effects on international affairs, both good and bad. For example, favorable returns result from providing navigation and traffic control functions to save a life or a vehicle of another nation. Bad effects result when undesirable objects fall within or near the boundaries of other countries as when a U.S. atomic bomb was lost off the coast of Spain. International tension can mount under certain circumstances, even if the country is friendly to the U.S.

An accurate NTC system would have other effects on international affairs; for example, it would help maintain the air and sea space rights of all nations by providing constant surveillance of all vehicles in the vicinity of national boundaries.

The difficulties of implementing an effective NTC system are not operational, technical, or economic; rather, they are political or organizational. The involvement of many international agencies and organizations and the lack of a central or a single authority having financial and program management control will delay the establishment of a much-needed worldwide satellite navigation system.[5,11]

National Security

Although military satellites were not considered in this analysis, navigation and traffic control satellites have important relevancy to national security. Obviously, military needs for navigation and position information could be satisfied partially through a common worldwide satellite navigation system. In fact, outside general aviation and small craft users of NTC, military vehicles will rely on readily available self-navigation systems.[16] Military requirements, however, are generally much more stringent in terms of accuracy, reliability, availability, and concealment. For example, navigation accuracy requirements for certain classes of missile-launching ships and submarines or for aircraft bombardment activities must be satisfied under adverse war conditions. A passive satellite navigation system would be desirable for military purposes. While costs would be important, they would not impose such great limitations as are imposed, for example, in commercial shipping.

It is most probable that the military services will continue to develop their own satellite navigation systems. The Navy already has its Doppler satellite system, which is also being used at the present time by scientific and commercial organizations. The Navy still has under active development a more accurate satellite navigation system called Timation. The Air Force is developing a ranging system utilizing 12 satellites for positioning aircraft. The Army SECOR satellite system, although it is primarily a geodetic location system, could be modified, if necessary, for navigation.

DOD goals for improving aircraft satellite navigation, communications, and intelligence relaying are

(1) To obtain smaller, more reliable airborne systems of higher performance at low cost through use of the emerging integrated-circuit technology.

(2) To obtain freedom from line-of-sight limitations.

In national emergencies when a country is in a stage of offensive or defensive alert, all commercial and civilian ships and aircraft are expected to support military functions. Therefore, an NTC satellite system could conceivably be of great value for national defense. The problem of traffic control for coordinating the increased air and sea transportation activities would be greatly intensified. When search and rescue operations were involved, the availability of a universal NTC system could be very important.

The military could benefit directly from application of the technology developed at NASA for the improvement of their navigation satellite systems. Also, they could benefit indirectly from use of NASA geophysical and meteorological data collection from satellites to increase the effectiveness of weapon systems.

Natural Resources and Environment

Successful exploitation of natural resources involves the availability of accurate maps and navigation capability which permits ships and aircraft engaged in surveying or exploration to return to the area of interest or discovery. Most present marine and land resources development program requirements are being met by other than satellite navigation means. The relevancy rating indicated in Table XI-3 confirms this except for two major objective areas involving sea navigation. The first is ship position determination, which rates as fundamentally relevant. Although other navigation means are available, in many instances an NTC satellite system would have advantages, most of which would pertain to low cost. The second, which is also rated as fundamentally relevant, pertains to data collection. At present, there is no satisfactory system for rapidly collecting environmental data from remote areas on a continuous and unattended basis. An NTC satellite system could provide needed data in real time.

Education and Knowledge

Although the NTC satellite program is an application program, advancement of the basic technology related to navigation, measurement systems, satellite orbital determination, communication and traffic control, and hardware development, is definitely of value in terms of national goals. Position determinations can be provided by other means, but improvement in space technology could make satellite methods competitive.[5] The utilization of certain communication channels (VHF, UHF, L-band) for navigation purposes would contribute to national goals related to education and knowledge. Studies of the effects of the ionosphere, troposphere, etc., involved in the NTC program can also contribute to knowledge.

At the present state of antenna technology, hemispherical all-azimuth coverage with adequate antenna gain appears to be difficult to achieve. Advances in semiconductors and microcircuitry and production of integrated circuits promise to revolutionize the industry. These developments make possible the combination of smallness, high reliability, functional flexibility, and comparatively low cost and, thus, also advance national education and knowledge goals.

Agriculture

The contribution of an NTC program to national agricultural goals is nominal. The NTC appears to be advantageous only in data collection and telemetry programs. Most other agricultural goals are being satisfied by other means. On the other hand, if fishing is considered under agriculture goal, then NTC can contribute to it considerably. In Japan, for example, design studies are being made to establish a satellite navigation system for the Pacific.[43] The primary user of such a system is the Japanese fishing fleet which requires ±1 n. m. accuracy in position determination.[39]

Future Flight Program

The NASA program in NTC is still in the definition stage. So far, this program has been limited to the execution of a few experiments aiming at selecting the most promising equipment rather than developing the satellite system per se.

Efforts in FY 1970 will concentrate on advanced experiments for concept evaluation and for a flight test definition program to confirm analytical findings.[10,19] These experiments will be concerned primarily with technical problems relating to system hardware and accuracy for air traffic control, and search and rescue operations. Two satellite launches are being planned for NTC of an integrated system mission spacecraft based on ATS-I and ATS-D.[8] Spacecraft size, weight, and configuration are still under study. Delta/TE-364-size spacecraft appear suitable. The launch schedule shows 1972 as the earliest, based on optimum considerations and beyond 1975 for austere considerations.[8] These launches are being planned to coincide with tests of SST and B-747-type aircraft. It appears, however, that delays are expected in both SST development and in NASA's NTC program because of budget constraints.

Future NASA studies will involve definition and analysis of new approaches particularly in L-band communication and satellite hyperbolic ranging.[17] This L-band system is in the middle of UHF, which will cause further difficulties and implications of both economic and political nature.[19] For example, most present airline equipment inventories are based on VHF. Therefore, use of UHF would require completely new instruments. France and the U.S.S.R. are favoring the use of UHF. Competing designs will still be made between multiple satellites or sequential satellite interferometer approaches substantiated by laboratory evaluation programs. Moreover, studies and experiments will be conducted on data relay and voice transmission via satellites in low orbits and at synchronous altitudes to the user craft.[7,10] Additional navigation and traffic control experiments will be made on ATS-I and ATS-III and on the Nimbus satellites to determine their capabilities.[5,7,8] Also future multimission spacecraft are expected to carry out NTC experiments.[8]

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