OUTLOOK FOR SPACE

Report to the NASA Administrator by the Outlook for Space Study Group

January 1976

NASA
National
Aeronautics and
Space
Administration

NASA SP-386

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Report to the NASA Administrator by the Outlook for Space Study Group

Prepared by
a Task Group consisting of participants from

Ames Research Center
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NASA
National
Aeronautics and
Space
Administration

Scientific and
Technical
Information
Office

Washington, D.C.
1976

For sale by the Superintendent of Documents,
U.S. Government Printing Office, Washington, D.C. 20402

"The significance of the adventure in space is that we are positioning ourselves for perceiving larger truths. Such truths can give us an enlarged sense of human purpose."

—Norman Cousins, Editor, Saturday Review World

"We are at a point in history where a proper attention to space, and especially to near space . . . . . . may be absolutely crucial in bringing this world together."

—Margaret Mead, President, AAAS

"I am firmly convinced that the time has come and the technology is available for the use of space as a new tool, combined with existing ones, to improve the conditions of mankind throughout the world."

—Jack Campbell, President, Federation of Rocky Mountain States

FOREWORD

The national program of civil space services and scientific exploration is evolutionary. As new opportunities appear – engendered by technological progress and scientific discovery – new capabilities to meet internal needs or external challenges become evident. In this environment, planning for the future is a continuous rather than static process, guided by technological realism and human aspiration and fitted to the overall priorities of the nation and the Federal Budget.

The study, *Outlook for Space,* was commissioned by NASA as one part of an overall program planning process. The task laid out for the Study Group was to identify and examine the various possibilities for the civil space program over the next twenty-five years – a horizon broad enough to permit bold projections but close enough to the present to demand realistic technical judgment. This report completes the Study Group's task and documents its findings, recommendations, and perceptions of the future.

I am pleased with the results. The Study Group, avoiding the temptations of trying to develop a rigid blueprint, has instead provided us a rich source for future plans. They have been conservative and rigorous in screening potential space activities against the criterion of "why should it be done and to what will it contribute?" rather than against the far easier test of simply "can it be done?"

The study report is a valuable contribution to the integration of civil space capabilities into the structure of human society. The Study Group has compiled an impressive analysis of the services that space systems and technology might provide the world of today and tomorrow, and has related this analysis directly to national needs and human purposes. Their catalog of potential missions outlines the unique opportunities for the scientific exploration of the universe and for pressing outward the frontiers of man's experience. Their study was not bounded by the limitations of NASA's responsibilities or even those of the Federal establishment; the report also covers many possibilities for multinational activities as well as areas clearly the eventual domain of commerce and industry.

The report itself is already being employed as a framework for the more detailed planning necessary to move forward the NASA component of these programs and projects. The study activity has also had an important influence both within and outside of NASA. It has opened new avenues of communication, illuminated new yardsticks against which to measure performance and contribution, and focused attention on the nature of the challenges and rewards still ahead. The effort has provided an intellectual catalyst and an institutional inspiration; the tasks before us are to translate promise into accomplishment, possibilities into practicalities, within the resources allocated to this important area of national endeavor.

As we proceed, we fully expect to find that we should not pursue every mission opportunity identified here; we expect as well to identify new concepts and tasks not previously addressed. As we now go forward, we will be using the Study Group's report as a very important guide to the direction of civil space development. The challenge which we all face now is to select, from the very wide range of activities studied here, those key missions and critical programs which offer the greatest values to human life and national capability. We have already begun turning the study into plans, and plans into realities.

The outline of the national civil strategy in space is clear. Our programs must focus on the main challenges of:

- Accelerating the deployment of economic and efficient space services for society
  - —— resources management, environmental understanding, and commercial returns from the unique contributions of space.
- Continuing the outreach of exploration
  - —— probing the history of the universe, understanding the physics of the stars, and searching for other life and cultures.
- Maintaining technological excellence
  - —— readiness to respond to national needs and opportunities on Earth as well as in space; capabilities to communicate and operate anywhere in space; means to manage vast amounts of information; and competence to explore new sources of energy.
- Expanding the human society beyond its planet Earth
  - —— reaching, probing, exploring to satisfy humanity's need to expand its horizons, to search for new worlds and new truths, to find its cosmic heritage and thereby assure its survival on Earth.

With appreciation for a difficult task well executed, I am pleased to release the final report on the *Outlook for Space.*

James C. Fletcher
Administrator

January 20, 1976

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PREFACE

The Space Age is now some 18 years old and a great deal has been accomplished by the United States and other nations; for example, human beings have walked on and explored the Moon, spacecraft have explored four major planets other than Earth, weather satellites are commonplace – the list is very extensive. It is appropriate, at the beginning of the last quarter of this century, perhaps the beginning of a new era in civilization, to ask such questions as: "Why should the United States be in space?" and "What are the key roles for space in our national affairs and in our national interests?"

To seek answers to these and other questions, Dr. James C. Fletcher, the Administrator of the National Aeronautics and Space Administration, assigned 20 individuals who, as a group, were knowledgeable in all aspects of space activities, to a one-year study. The outlook for all civilian space activities was to be examined – not just what NASA might do, but also potential operational uses and commercial interests.

This report and the separately published Technology Forecast are the results of the Study Group's efforts. The contents of these reports are endorsed by all of the Study Group members. Still, it should be appreciated that ours is the only endorsement: The reports and their findings are not necessarily the position of the National Aeronautics and Space Administration or of other individuals or organizations.

Hundreds of individuals provided supporting information and viewpoints. The listing in Appendix A is an acknowledgment of our appreciation for their contributions, and is not to be construed as indicating their agreement with the content of this report.

In order to regard future space activities in the broadest possible context, we decided to examine many United States and world trends as they are viewed by various individuals and organizations who study societal, economic, and political futures. The trends cited in this report represent what we heard and read during the course of the study that had a significant influence on our thinking.

It should not be surprising that we present no *new* ideas about what might be done in space. The world abounds in imaginative people, and the catalog of what might be done in space is immense. What we have done is to identify some of those possibilities which are within reach over the next 25 years and, most importantly, can contribute in a significant way to the needs of peoples and nations.

Donald P. Hearth
Study Director

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CHAPTER 1

INTRODUCTION

BACKGROUND

In June 1974, Dr. James C. Fletcher, the Administrator of the National Aeronautics and Space Administration, initiated a planning study entitled "Outlook for Space." The purpose of the study was to examine future space activities within the context of possible national needs, and to identify directions the United States should take in the civilian use and exploration of space for the remainder of this century.

The specific objectives of the study effort were:

1. *To develop an unconstrained listing of desirable and practical civilian space activities for the time period 1980 to 2000.*
2. *To group these activities around central goals, objectives, and themes.*
3. *To define the research and development tasks required by potential commercial and operational uses of space.*
4. *To identify social and economic national challenges which can benefit from space exploration and research.*
5. *To relate the goals and objectives of civilian space activities to national goals and objectives.*

Dr. Fletcher also provided the following guidelines for the Study Group:

1. *To highlight the period 1980 to 1990.*
2. *To solicit and thoroughly examine the views of groups and individuals outside of NASA.*
3. *To assume the current NASA program will continue as projected for the next five years.*

In late June 1974, the Study Group was formed consisting of 20 people from the NASA Centers and Headquarters, and a representative of the U.S. Air Force. We were assigned to the study effort for a significant amount of time while retaining our normal positions at our regular work locations. For the purpose of the study effort, we were considered to be detached and were not to represent our parent organizations. We adopted the following overall approach:

1. Future space activities would be examined within the context of future external environments (social, economic, political, scientific, technical, etc.) having a high probability of occurring, given today's environment and projected developments during the next quarter century.

2. Emphasis during the study would be placed upon identifying and evaluating future space activities from the standpoint of "objectives." The means of implementing the objectives through specific systems would be a supporting consideration, necessary to estimate the achievability of the objectives and the resource implications.
3. Future space activities would be examined by first establishing why they should be undertaken, then defining what could be done in space in response to the objectives, and finally how such space activities should be pursued.

We were instructed *not* to develop detailed mission/program plans for the U.S. during the next several decades, i.e., not to recommend specific missions to be conducted at given times consistent with finite resource limitations. Rather, our task was: to identify future objectives of space programs and to prepare background information which could serve as a basis for the subsequent development of program plans. We have proposed examples of program elements to illustrate use of the study's results.

The results of the study contain an extensive, but not necessarily a complete, set of attractive objectives for space activities. About 250 systems* were identified as *illustrative* means of pursuing the objectives. However, there was no attempt to identify all possible space missions and systems which might be conceived of as means to achieve the objectives.

STUDY APPROACH

The study approach is shown in Figure 1. Working groups and teams were formed to carry out elements of the study. The members of the working groups and teams are listed in Appendix A.

We defined two categories of human needs, namely, humanity's physical needs, and its need to understand its place in the Universe, to understand the Earth, and to be challenged. Physical needs include the provision of food, shelter, health, security, education, a good environment, and the work necessary to obtain them. Higher-level attainment of such needs represents a key element in the enhancement of the quality of life. The need to understand and to be challenged is also germane to the quality of life, and includes the quest for knowledge, the need to explore and understand the unknown, and the sense and recognition of accomplishment in the face of challenge.

We developed the objectives on a "geographical" basis; those which are Earth-oriented (pertaining to activities orbiting and interacting with the Earth) and those which are extraterrestrial in emphasis. For the next 25 years, we expect that Earth-oriented objectives will address, for the most part, physical needs and the need to understand the Earth, while the extraterrestrial objectives will be concerned with the need to understand the Universes. As the latter are achieved and our

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*A "system" is defined as spacecraft or ground-based information activity, or a combination of the two, or necessary laboratory work. A single system may involve several space flights.

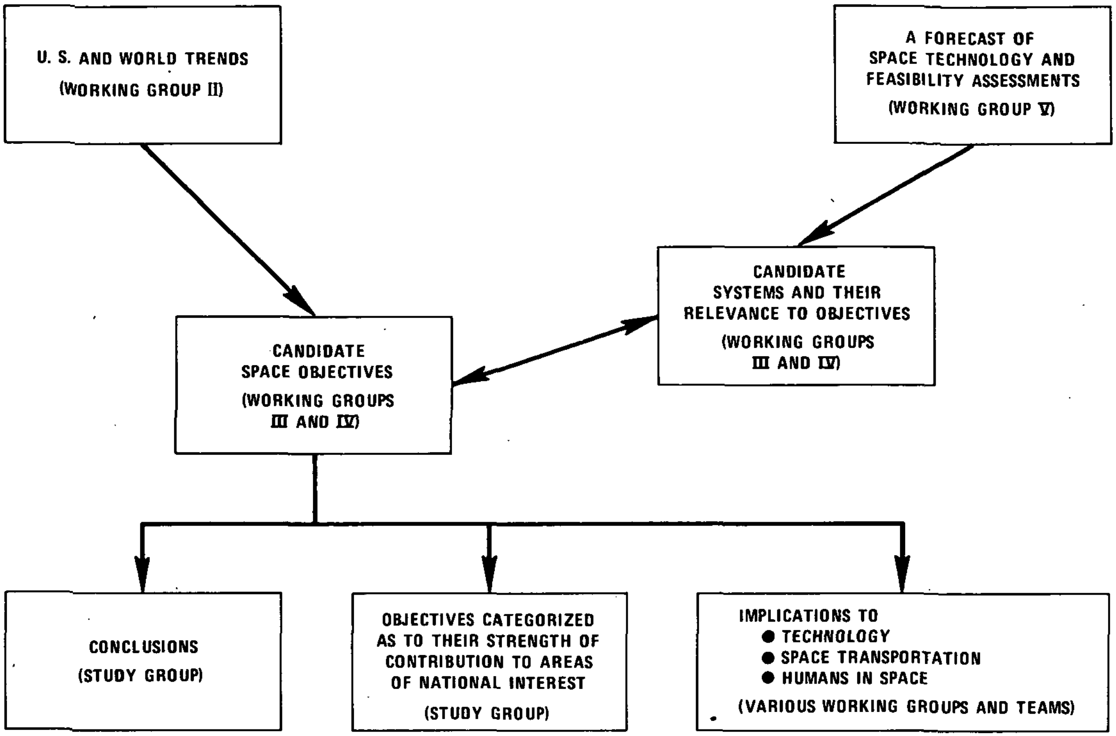

Figure 1. Study Approach

understanding of what is now unknown improves, extraterrestrial activities may also become responsive to physical needs in the future decades and centuries.

The Earth-oriented objectives are grouped into seven themes, the first six responding to physical needs and the seventh to the need to understand the Earth. The extraterrestrial objectives, grouped into five additional themes, address the need to understand the cosmos and our relationship to it.

The technology effort was carried out by means of a task order to the Jet Propulsion Laboratory which was, in turn, supported by many of the NASA Centers. The outputs of the technology effort were: (1) a forecast of space-related technologies to the year 2000, (2) feasibility assessments of candidate systems, and (3) the identification of "preparedness technology" for the future.

One of the objectives of the Outlook for Space study was to organize concepts of future space activities in such a way that they could be evaluated against national goals and objectives. This was in recognition that space activities are funded largely with public money and must, therefore, relate to the public interest. To meet this objective, we defined seven areas of "National Interest" which we felt to be representative of the interests held by individuals and groups in this country. All of the themes and objectives previously described as being worthwhile were evaluated in each of the areas of national interest. The results of this evaluation represent the opinions of some members of the Study Group in May 1975 – individuals with scientific and engineering backgrounds and with varying degrees of management, public service, industrial, administrative, and academic experience. Over the period of the study, the evaluation changed, and the group's evaluation would probably continue to change with time as new information became available and our perception of national needs change. Still, we believe the evaluation to be a generally valid estimate of the way U.S. society would perceive the successful achievement of the candidate objectives. For that reason, it should serve as a useful guide in understanding the relationship between various space activities and the public interest.

It should be noted that throughout the report, cost information is based on 1975 dollar values and the term "current" means circa 1975.

EXTERNAL SOURCES

External inputs were used extensively in the study. We considered previous studies by groups such as the Space Science Board of the National Academy of Sciences. In addition, over 40 organizations provided formal inputs and hundreds of individuals were consulted for their views and opinions. Appendix A lists groups and individuals from outside the Study Group who provided inputs to the study. Near the completion of the study, we held reviews with many of the organizations that had previously provided input. Our purpose was to indicate the tentative results reached by the study, the utilization of the input provided by the particular group, as well as to solicit comments and criticisms.

In order to broaden our perspective and to provide background information, the Smithsonian Institution conducted a week-long seminar during late September 1974. About 30 individuals, both U.S. Government and non-government workers, including writers, economists, sociologists, diplomats, historians, experts in food, energy, communications, genetics, computer science, international affairs, etc., participated with the Study Group in the seminar (see Appendix A).

To sample the views of young people, the NASA Headquarters Office of Public Affairs arranged for a survey of 15,000 high school and college students by Oklahoma State University. During December 1974, the students provided their views relative to (1) national challenges facing the U.S. in the next 25 years, (2) future space activities deemed important, and (3) the contribution of past space activities.

The following contracts were also established:

Forecasting International and the Futures Group – to compile and analyze available information on future U.S. and world trends and to provide background information on technology forecasting methodology.

The George Washington University – to examine the historical activities of societies in the area of exploration.

The Hudson Institute – to analyze available data taken by nationally recognized polling organizations in order to gain insight into the attitudes of the American public toward the space program.

STUDY PRODUCTS

The written products of the study, which are or will be available on a limited basis, are:

- "Outlook For Space: Report to the NASA Administrator by the Outlook for Space Study Group," NASA SP-386, January, 1976.
- "A Forecast of Space Technology, 1980-2000," NASA SP-387, January, 1976.
- A Synopsis Report of the Study
- Contractor Reports
  - "The Future Environment: U.S. and World Trends," Forecasting International/The Futures Group. Washington, D.C., July 15, 1975.
  - "Implications of Public Opinion for Space Program Planning, 1980-2000," The Hudson Institute, Croton on Hudson, New York, 1975.
  - "The Exploration Ethic, Its Historical-Intellectual Basis," The George Washington University, Washington, D.C., 1975.
  - Edited Proceedings of the Outlook for Space Seminar, Hammersmith Farm, Newport, Rhode Island, September 30-October 4, 1974, The Smithsonian Institution, G. S. Robinson and P. Porney, Eds.

REPORT ORGANIZATION

This report is organized into nine Chapters and three Appendices as follows:

Chapters

1. Introduction
2. The Study Conclusions. The conclusions reached by the full Study Group at the end of the study.
3. Space in Perspective. A historical review of space activities obtained from interviews and the writings of various observers of space over the past decades.
4. U.S. and World Trends. A summary of representative information obtained by the Study Group, its consultants, and its contractors on possible future U.S. and world trends.
5. Potential Space Activities. This chapter treats each theme, all of its objectives, and the programmatic implications of pursuing the objectives.

6. Three Exciting Opportunities. This chapter indicates how the material provided in this report might be used for formulating future programs. Examples of three possibilities are included.
7. Exploring and Developing the Space Frontier. A number of more advanced space activities are discussed. They are treated separately from those in Chapter 5 because of a combination of size, apparent need, technical feasibility, clearness of timing, etc.
8. The Contribution of Future Space Activities to National Interests. This chapter summarizes the results of evaluating the contributions of the themes and objectives identified in Chapter 5 to Areas of National Interest as defined by the Study Group.
9. Implications on Space Transportation, Human Flight, and Technology. The activities of Chapters 5 and 7 have broad implications for the future, often requiring new capabilities. They include implications on technology, space transportation, and human operations in space. This chapter is devoted to these considerations.

Appendices

A. Contributors. This appendix identifies those individuals who were involved in the study effort on a sustained basis, on a discussion basis, or who provided inputs to the study in some way.

B. Systems. This appendix identifies and describes illustrative systems for pursuing the objectives discussed in Chapter 5.

C. Technical Feasibility. This appendix identifies the present state of technology and required advances in technology which will pace the development of the various systems needed to pursue the objectives described in Chapter 5.

We feel that Chapters 3 and 4 are a desirable background for the rest of this report. The reader may, however, wish to proceed directly to Chapter 5, and review Chapters 3 and 4 subsequently.

CHAPTER 2

STUDY CONCLUSIONS

As we examined the situations which are likely to challenge humanity during the next several decades, we found it natural to separate them between those which must be solved to satisfy man's physical needs and those which deal with the needs of his mind and spirit. The first two groups of our conclusions deal with these two areas. These are followed by our conclusions on research and technology and, finally, by a statement regarding the relationship of the space program to national needs and of the importance of public perception of that relationship.

I. The great challenges facing the physical needs of humanity are principally the result of the continuing struggle to improve the quality of life. Particularly critical is the need to improve food production and distribution, to develop new energy sources, to meet new challenges to the environment, and to predict and deal with natural and man-made disasters. In each of these areas, we found that significant contributions can be made by a carefully developed space program. The Study Group reached the following specific conclusions:

1. *A major increase in emphasis and in resources should be directed toward Earth-oriented space programs.*
2. *Among humanity's needs which are particularly amenable to the use of space-derived data are monitoring and prediction of climate and severe weather, prediction of crop production and water availability, and monitoring of changes to the environment.*
3. *The increasing shortage of available energy warrants an intensive investigation of the technical, economic, and environmental feasibility of space power generation and hazardous waste disposal in space.*
4. *The transition between the research and development of space systems for Earth-oriented needs and the operational use of these systems is critical. Planning for this transition should be an integral part of the earlier phase and will require substantial resources.*
5. *The multiple-use of operational, remote-sensing spacecraft will be necessary to economically exploit the utility of the nation's Earth-oriented space program. The development and management of these spacecraft will require broadened and innovative cooperative arrangements between government agencies at the federal, state, and local levels as well as between government and the private sector.*

II. Human needs are not only physical. The human mind, which sets us apart from other species, is capable of dealing with abstract concepts and of consciously influencing the future. There is therefore a need for intellectual challenge, for exploration, and for the knowledge by which man can better understand the Universe and his relationship to it. Space programs have and will continue to make contributions to these needs. The Study Group reached the following specific conclusions:

6. *The space science program of the future should continue exploratory research but should increasingly be focused on specific objectives selected on the basis of their expected contribution to fundamental scientific questions.*

7. *Scientific questions of particular current significance deal with the beginning of the Universe; the nature of black holes and quasars; gravity; the evolution of the planets and their atmospheres; the nature of the Earth's climate; and the search for extraterrestrial life, including intelligent life.*

8. *Social, economic, and technical forces will one day cause man himself to further explore and exploit the solar system.*

III. Although many of the systems and missions required in a future space program are within today's state-of-the-art, research and technological advancement are required to achieve cost effectivity, basic feasibility for many of the possible systems, and preparedness for future opportunities. The Study Group singled out a number of areas of technology which represent particularly pressing needs and reached the following specific conclusions:

9. *A major increase in attention and resources should be directed toward data management and information extraction.*

10. *There should be increased emphasis on theory, development of predictive modeling, and data analysis in support of future space missions.*

11. *The United States needs to maintain its international leadership in space communications and, therefore, should increase its efforts to advance communications technology and to develop and demonstrate new uses.*

12. *An active program should be pursued to exploit the zero-gravity environment of space to increase the understanding of material science and basic physical, chemical, and biological processes.*

13. *The United States should develop a permanent Space Station to fully exploit the zero-gravity environment of space for basic research, to develop a full understanding of the ability of man to live and work in space for extended periods, and to provide a potentially useful instrument of U.S. foreign policy.*

We recognize that future space programs must provide a service to the public – and if space is to have an opportunity to make its contribution, it must be recognized as fulfilling a public need. We also recognize that in many instances the public has inadequately understood the contributions which space can make to the physical needs of mankind, to the quest of the mind and the spirit, to the vitality of the nation, and to the relationships which exist between this nation and other nations of the world. To the extent that this is so, the burden rests on those involved with the space program not only to explain the virtue of the program to the public, but, more fundamentally, to plan and conduct the program so that it truly responds to the needs of people and nations.

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CHAPTER 3

A PERSPECTIVE ON THE INITIAL YEARS OF THE SPACE AGE *

INTRODUCTION

In order to examine the potential and need for space activities in the United States for the remainder of this century, it seemed appropriate to review the events that brought us to this juncture. Reflecting on the last 30 years permits us to briefly summarize, for the purpose of this study, the essence of our past experience, as well as the consequences of space activities for contemporary society – both in the United States and in the world at large.

The documentation of space experience and its significance is vast. It is not appropriate to include a comprehensive review of this material here. However, it is appropriate to review the space program in its major phases, to examine its impact on American life, and to understand better the forces within American society that influenced its directions. To establish this perspective, we examined our own experience and interviewed a number of additional participants and students of the space program. These viewpoints were supplemented by a review of writings by scientists, social observers, and journalists who have studied the space program in the light of concurrent changes in public opinion.

Selected material from these sources is presented in two parts. First, a highly selective historical summary focuses on the four phases of space-related activity which seem to have had the greatest influence on the current scope and meaning of these endeavors. The second part is a limited examination of this history from the viewpoint of a number of national interests. The final part of this chapter briefly considers space experience with respect to: the advancement of knowledge; the significance of exploration; the needs and concerns of the American and other peoples of the world; the vitality of the U.S. as a nation; effects on international cooperation and understanding; and the significance of these beginning ventures in space – what space may mean, or seems to begin to mean, for humanity's view of its own nature, its place in the cosmic scheme, and its destiny.

FOUR PHASES OF THE SPACE PROGRAM

1945 to 1957

Although the theory of space flight had been developed early in this century, the first practical steps into space were possible only after advancements in rocketry, accelerated by World War II, led to two parallel developments in the immediate

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*As noted in Chapter 1, readers who wish to defer Chapter 3 until a later time and proceed directly to Chapter 5 can do so without loss of continuity.

postwar years: launch vehicles large enough to lift payloads first above the atmosphere and then into orbit, and growing acceptance of space as a promising area of exploration and discovery. The V-2 weapon of World War II was a major departure from the earlier small-scale rocket experiments. The work of the German engineers and scientists at Peenemünde, followed by rocketry development in the U.S. and the USSR, shaped a period in which space efforts had potential scientific and military meaning. American and Soviet rocket technology took two separate roads. In the U.S., the development of thermonuclear weapons made it possible to build lighter, yet more powerful, warheads than the device that was dropped on Hiroshima. As a result, early plans for very large missiles were modified and development began on smaller rockets, more in keeping with warhead size. The Soviets, proceeding less rapidly in thermonuclear technology, initiated development of larger missiles which, fortuitously, put them in a better position to make the first move into space.

Until about 1950, western interest in space exploration was centered in small groups of scientists from various military research laboratories, plus groups such as the American Rocket Society and the British Interplanetary Society, which included academic people and enthusiasts from other fields. Scientific efforts went forward in probes of the upper atmosphere using V-2s, as well as newer vehicles such as the Wac Corporal, the Viking, and the Aerobee-Hi.

As early as 1945, a small informal panel of scientists from the military and from a few universities had begun meeting to pool their findings and to plan future rocket-launched experiments. This group, without any official charter, continued to be the focal point of thought regarding rocket and space research development well into the 1950s. But that collection of experience became central when, in 1955, it was proposed that the U.S. launch a satellite in connection with the International Geophysical Year, which was to begin in 1957.

1957 to 1961

On October 4, 1957, the space age began as the Soviet Union launched the first Sputnik. A rapid flow of events began immediately. Actions taken in the following few months shaped the space effort well into the next decade, and, in some respects, up to the present. Among these actions were: the launching of a second, much larger Sputnik on November 3, 1957 (carrying the dog Laika); a Congressional inquiry into U.S. space efforts, organized November 4, 1957; the appointment of the first scientific advisor to the President three days later; permission, on November 8, 1957, from Secretary of Defense McElroy, to use a military rocket to launch a satellite. Then, on December 6, 1957, only seconds after liftoff, a first-stage propulsion failure destroyed the first full-scale test vehicle of the U.S. Vanguard satellite program. That event intensified discussion in Congress and in the media on why the U.S. was lagging in this area of high technology, what the Soviet edge in space signified, and what could be done about establishing U.S. superiority in this suddenly crucial field of advanced science and engineering.

There was extensive questioning by opinion leaders regarding America's allegedly superior science and technology, the capabilities of U.S. education, and the impact on national morale of the U.S. suddenly being in second place. An analysis of public opinion polls from this period concluded that post-Sputnik opinion about the position of America versus Russia in space "did not indicate immediate unanimous psychological shock" since the general public, for the most part, did not clearly understand or comprehend what a satellite of Earth was, what it portended, or what was necessary to accomplish such a feat.

Space advocates in Congress and the armed services, joined by those scientists who had long hoped for greater efforts in space, began fashioning a response to the Soviet challenge, amid strenuous debate about what should be the military/civilian relationship in space efforts and whether the U.S. space effort should be coordinated by a scaled-up version of the largely research-oriented National Advisory Committee for Aeronautics (NACA) or by some totally new arrangement. White House and scientific insistence on a civilian focus for space prevailed; legislation was passed and signed in the summer of 1958, creating the National Aeronautics and Space Administration (NASA), which incorporated the NACA and the Vanguard team. Goals for the space effort stated in the National Aeronautics and Space Act emphasized scientific and technological developments, use of discoveries with significance for national security, use of knowledge gained in the military space effort by the civilian program, international cooperation, coordination of the nation's scientific and technical resources with respect to space, and wide dissemination of technical information for benefits to mankind.

Some of the factors which affected the way in which the U.S. space effort got under way were:

- The challenge to U.S. technological preeminence posed by the Soviet achievements
- National pride, expressed by the public and Congress
- The relationship to national security, real and apparent
- Views on the space effort expressed by leading scientists
- The amount of technological knowledge needed to implement various projects that might be undertaken
- Resources available in government, universities, and industry, as well as the effect on those institutions of becoming heavily involved in a space effort

Throughout this period, space spectaculars were almost exclusively Russian – several lunar probes and, in 1961, the first orbiting of a human being about the Earth. It is only now, in retrospect, noted that the first two U.S. satellites, Explorer I and Vanguard I, launched a few months after Sputnik II, both made discoveries of major scientific importance: the Van Allen radiation belts and the slight "pear shape" of the Earth.

1962 to 1969

It became an aim of the new Administration to establish U.S. preeminence in the "new ocean" of space. The proposal for a manned lunar landing by the end of the decade provided a focal point for this effort. After strong advocacy by the President, Congress endorsed the idea. But, as James Webb was to emphasize just before retiring as NASA Administrator, this commitment was conditional on year-to-year review by Congress, since the 1958 NASA Act called for virtually constant program review as part of the annual budgeting process.

The goal of a manned lunar landing gave NASA a cohesive, goal-oriented plan that captured the interest of the public and Congress. Between 1959 and 1967, spending for manned space flight rose from 25% to 75% of NASA's R&D budget. During the early part of this phase, the U.S. began to emerge with successful firsts of its own, particularly in the area of sending automatic unmanned spacecraft to the planets, a feat which the Soviets had difficulty in accomplishing. This period inaugurated the U.S. manned space program: Mercury, Gemini, and Apollo, and culminated in the July 1969 lunar landing. As our successes grew, so did the debate over such matters as adequate attention to science and to Earth applications of space, and to adequate emphasis on research and development.

A public debate began on the justification of the space effort as a high national priority, in view of the urban and cultural turmoil in the U.S. and its foreign involvements. From the perspective of the nation as a whole, space efforts were only one of a number of national preoccupations. There was particular criticism of space activity in 1963 and 1964 and again in 1967, when a fire during an Apollo test caused the death of three astronauts. Another factor eroding the enthusiasm of some Americans for a manned lunar landing was that the Soviets, after the mid-60s, no longer seemed to be competing for this particular space objective.

When the lunar landing was accomplished, the size of this achievement, its unprecedented nature, and the consequences to humanity were difficult to fully comprehend. It was recognized as a profound accomplishment, but its significance was not widely or immediately appreciated.

In 1969 the goals and detailed programs for the period to follow Apollo were yet to be defined. The Agency and efforts in space generally were vulnerable to opposition or competition for funds from other Government endeavors. On the other hand, by 1968 the nation was in very different circumstances from the days when Apollo began; program proposals, no matter how well-defended on grounds of scientific advances, national prestige, national security, etc., did not enjoy the support of the early 60s. After mid-1969, NASA leaders were engaged in a hard struggle to win acceptance of a balanced program of manned flight, science, applications, and advanced technology.

The lunar landing, massive and unique, was only possible because the technologies were available at the time, there was strong advocacy at the highest level of national leadership, and there was enough public consensus to mobilize the necessary talent and funds – a consensus, perhaps that could not have been achieved for another national objective in that time period.

Into the 1970s

It became clear in the early 1970s that, whatever the space program would become, it would probably not enjoy the unique conditions that encouraged intensive activity in the late 1950s and culminated in the landing on the moon. It also was apparent that, if the nation were to fully utilize the potential of space in the solution of national and global problems, a major reduction on cost was needed. In early 1972, NASA was authorized to proceed with development of the Space Shuttle, which promised to lower the cost of transportation and to make possible entirely new concepts of space operations. This decision was followed by the decision in Europe to develop the Spacelab, and, more recently, by the Department of Defense decision to develop a propulsive upper stage to augment the shuttle for high altitude payload delivery.

As these developments got underway, there was dramatic and constantly accelerating applications of space-derived scientific and engineering knowledge. The study of the moon, planets, sun, and stars; Skylab; Earth Resources Technology satellites; and communication satellites; all illustrate this pattern. But these achievements, and what they promise for the next quarter-century, are far from the center of public consciousness today. It is as if the drive to the moon was an imperative that took all of our attention, and that the time had come again to determine, as was the case in the late 1950s, just what the goals, scope, and pace of the space effort should be.

The relevance of space to human concerns generally is now easier to perceive than it was even 10 years ago. Most of the knowledge obtained so far from efforts in space is more than the exclusive concern of a single nation, or of only nations with enough resources to underwrite space activities. If it hadn't been for the concentration of technology, skill, accelerated experience, and high visibility which was both the cause and consequence of space efforts in the 1960s, this capability would not have been obtained. Now comes an even greater challenge for space activities – one that is broader than that which resulted in the focused response that culminated on the moon.

CONSEQUENCES

Knowledge

As a result of probes into space over the past 30 years, there is now a wide spectrum of space sciences and technologies, most of which would have remained undeveloped without the fundamental advances in propulsion, electronics, materials, and managerial techniques which space ventures require. Consequences of new knowledge from space is increasingly important for all of the natural sciences and engineering specialties, not only in terms of experimental technique, hardware, and data, but in terms of theory and strategies for further discovery.

It seems particularly significant that the explosion of space knowledge coincides with fundamental shifts and advances in other fields of science and technology. There was not only a "knowledge explosion," but the beginnings of a new perspective toward knowledge. Some scientists believe that these changes create the possibility, for the first time since the 18th century, of a new era of natural philosphy, providing humanity with new comprehension of cosmic processes, matter, the Earth, and life itself.

Space activity has broadened our view of the Earth, the solar system, and our place in the scheme of things. This coincided with a broadening perspective in geophysics (plate tectonics and continental drift); astronomy (quasars, black holes, a larger universe than had been thought of before); and biology (breaking of the genetic code, DNA, RNA). During the 1930s, 40s, and 50s, there was vigorous activity in science, but it was highly specialized, and in the public view, esoteric. There is, as a result of the concurrence of space findings and the broadening scientific perspective, a tendency to return to the spirit of natural philosophy of two centuries ago.

Paradoxically, the knowledge explosion related to space, while vast, is only beginning. Its impact on the world of science and technique generally, and on society as a whole, is just beginning to be realized.

Exploration

Space is a human adventure, even for those who never will fly above the atmosphere or understand the flood of discoveries which comes from looking back at the Earth or out to the stars. As in earlier periods of intense exploration, there is great interest even for those who stay on Earth or never benefit directly from the results.

In some respects, the initial phases of space exploration seemed no more relevant to our modern problems than Columbus' voyages seemed to the battle between Christianity and Islam occurring at the same time on the Iberian Peninsula. Yet the exploring nations of Europe soon became the undisputed leaders in the world. Whether it was cause or effect is not clear, but the two events have, historically, gone hand-in-hand.

Would the urge to explore space have been expressed without the stimulus of earthly competition, spurred by national rivalry as well as by curiosity? Perhaps not; certainly not so soon. And only certain kinds of individuals and nations are explorers. There is evidence, as studies of the "exploration ethic" have shown (Reference 1) that the motivation to explore is a critical variable associated with the vitality of societies and their long-term survival. This seems especially true in the present time of unprecedented rates of change, and of change with global impact. It remains to be seen whether the motivation to explore exhibited in the space effort will influence man's struggle to seek new means of survival on the Earth.

Concerns of the U.S. Citizen

As with the impact of scientific knowledge and technology on society, it is not possible to definitively describe how space efforts have related to the concerns of people in general. Weather and communications satellites have already made visible impacts on society. Additional impacts are surely yet to come, both in belief and in changed material circumstances.

The technological frontier is remote from the direct economic concerns of most Americans. The fraction of the public that is aware of space is small when compared with the fraction that was influenced by the introduction of the railroad, the automobile, and air flight. Therefore, to understand popular attitudes toward space, it is necessary to go far beyond explicit, rational calculations of profit and loss. It is necessary to discover how collective images of space exploration comport with existing modes of belief.

Curiously, the success of space efforts, culminating in the lunar landing, seemed to have raised in the minds of many, a false expectation embodied in the frequently voiced expression: "If they can go to the Moon, why can't they . . .?", reflecting criticism of the lack of progress in many other areas of material need. In polls of public attitudes on national priorities, space has ranked high on the list only once – immediately following the first Sputnik. Now, despite fundamental advances achieved or in prospect by space activities in resource management, communications, weather monitoring, and other fields clearly relevant to earthly needs, the connection of space with the concerns of the average citizen in the United States seems harder for him to make.

The most striking effects of the space experience are likely to come in the years just ahead, as humans who have lived entirely within the space age become adults. We do not know yet what kind of a society it will be in which space is regarded as a natural arena for human endeavor and for the solving of human problems.

Vitality of the U.S. as a Nation

Venturing into the unknown, whether on land, sea, or in space, has proved to be one of the most constructive ways in human history for demonstrating the prowess of a people. During the 1960s, success in space was among the relatively little good news the society could give to itself in a time of national turmoil and self-questioning. But was space a symbol of the triumph of technology over the human condition, or merely a demonstration that technology could enhance national well-being? Both views were proposed around the time of our seeming greatest triumph, the lunar landing in 1969; and the debate continues today.

Perhaps national vitality, like the pursuit of happiness, is not a goal which this or any other nation can strive for directly. And perhaps only in the long historical perspective can the relative vitality of individual nations, and the cause of that vitality, be judged. Yet it is clear that the acceptance of challenge, and the successful struggle to meet that challenge, constitutes a significant measure of national vitality.

Space and the Spirit

Whether or not space has had the most significant impact of these past 30 years on humanity's view of itself and its place in a cosmic scheme is difficult to assess. It cannot be denied that space makes possible a greater likelihood of a cosmic vision and perspective for humanity. It is not unreasonable to believe that future historians will write of the early days in the space age as the dawn of a new era in our understanding of the Universe and of our place in it.

CHAPTER 4

U.S. AND WORLD TRENDS*

INTRODUCTION

In order to develop a better understanding of the future environment as it may affect the need for and receptiveness to space activities, the Study Group sought an insight into the future of American society and the world as a whole.

Although we are all, to varying degrees, students of past and current history, and national and world affairs, we do not claim an expertise in predicting future sociological, economic, or political trends. We therefore sought the views of economists, sociologists, diplomats, historians, philosophers, lawyers, forecasters, and recognized experts in the areas of food, energy, communications, behavior, science, and international affairs. We also obtained inputs from a number of organizations whose main purpose is to analyze events and opinions, in an effort to discern the directions in which this country and the world seem to be moving. Also, a survey of the attitudes of some 15,000 high school and college students concerning the challenges facing the U.S. and the past accomplishments and desirable future objectives of the space program was used as background material.

We are very conscious of the limitations of predicting the future, particularly in the fields of economics and the political and social sciences, all of which will undoubtedly have a significant consequence for space flight – perhaps more than the scientific and technological abilities to carry out a particular space program. Yet, we believe that the understanding we were able to acquire of the events and changes taking place in the world helped us to identify objectives and evaluate the contributions that space might make in the future.

The purpose of this chapter is to summarize our understanding of some events that are changing the pattern of life in America and in the world, and to suggest how these changes might affect the future. In this discussion, we have concentrated on trends which we believe will influence the space activities this nation will undertake; we have not attempted to develop a total picture of world trends. The numerical data which appear in this chapter are derived from Reference 2.

OVERVIEW

Strong trends, which have taken a long time to develop, have resulted in a host of simultaneous crises, with rapid changes in social patterns both at home and abroad. Current difficulties always seem the most important, yet the implications of population growth, affluence versus poverty, increasingly destructive war-making

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*As noted in Chapter 1, readers who wish to defer Chapter 4 until a later time and proceed directly to Chapter 5 can do so without loss of continuity.

capabilities, and the rising expectations of people throughout the world have been known for a long time. It is the exponential growth in many of these situations that has produced what are perceived to be the crises of today and those to come.

The prevalent vision of the future, cloudy as it may be, has until recently been based on an acceptance of continuing growth: in the economy; in consumption of food, resources, and energy; in government; and in standard of living. Although experts have long recognized that exponential growth cannot continue indefinitely, the broader recognition of this fact now permits us to list a group of generally well-accepted areas in which changes must occur in the years ahead.

ILLUSTRATIVE TRENDS

The trends discussed in the following paragraphs are illustrative. They were drawn from the literature listed in the Bibliography at the end of this volume. Their order is not significant.

Energy and Economic Growth

Energy consumption in the United States and around the world has increased dramatically since the end of World War II. In the United States it has grown at a rate of about 4.4 percent annually since the early 1960s and now stands at about 70 quadrillion BTUs annually. Per capita consumption has steadily grown in all sectors, rising in the aggregate by about 2.8 percent annually since the early 1960s. To meet these growing demands, importation of energy began to increase rapidly in the early 1970s, and until recently, capacity plans were based upon importing about one-third of our energy by the year 2000. The recent price setting action by the Organization of Petroleum Exporting Countries (OPEC), has now forced a total reevaluation of our national energy policy.

Factors affecting the future relationship between energy supply and demand include the following:

- National energy demand is expected to continue to increase at a rate of approximately 3 to 4% per year until beyond 1980.
- Domestic crude oil production appears to have peaked in 1971. Projections (which include the North Slope) are for domestic crude oil production to remain approximately constant over the next 15 years.
- Domestic natural gas production peaked in 1971 and is projected to decline, while the estimated amount of natural gas yet to be discovered has decreased.
- There have been delays in bringing nuclear power on line due to environmental concerns and engineering difficulties.
- Recent environmental laws restricting the burning of high-sulfur coal place an extra burden on the use of oil and natural gas.

- Environmental pressure has delayed the construction of refineries and other energy-related facilities.

The compound effect of these factors points toward increased petroleum imports. However, the prospect of importing ever-increasing amounts of petroleum has two major adverse consequences: it implies growing dependence on foreign nations for a material which is intimately bound to our well-being and national self-determination, and it leads to an unfavorable balance of trade (in 1974 alone, the United States spent about $28 billion on imported oil).

The level to which consumption can be reduced without impinging unduly on the country's economic health is difficult to define because the precise relationship between the cost and availability of energy with economic performance is largely unknown. The economy of the United States and the other technologically advanced nations is strongly based on energy, however. Energy is the ultimate resource which permits the continued recycling of other resources into most of man's requirements for food, clothing, and shelter. Figure 2 illustrates the historical relationship in the United States between GNP and energy consumption.

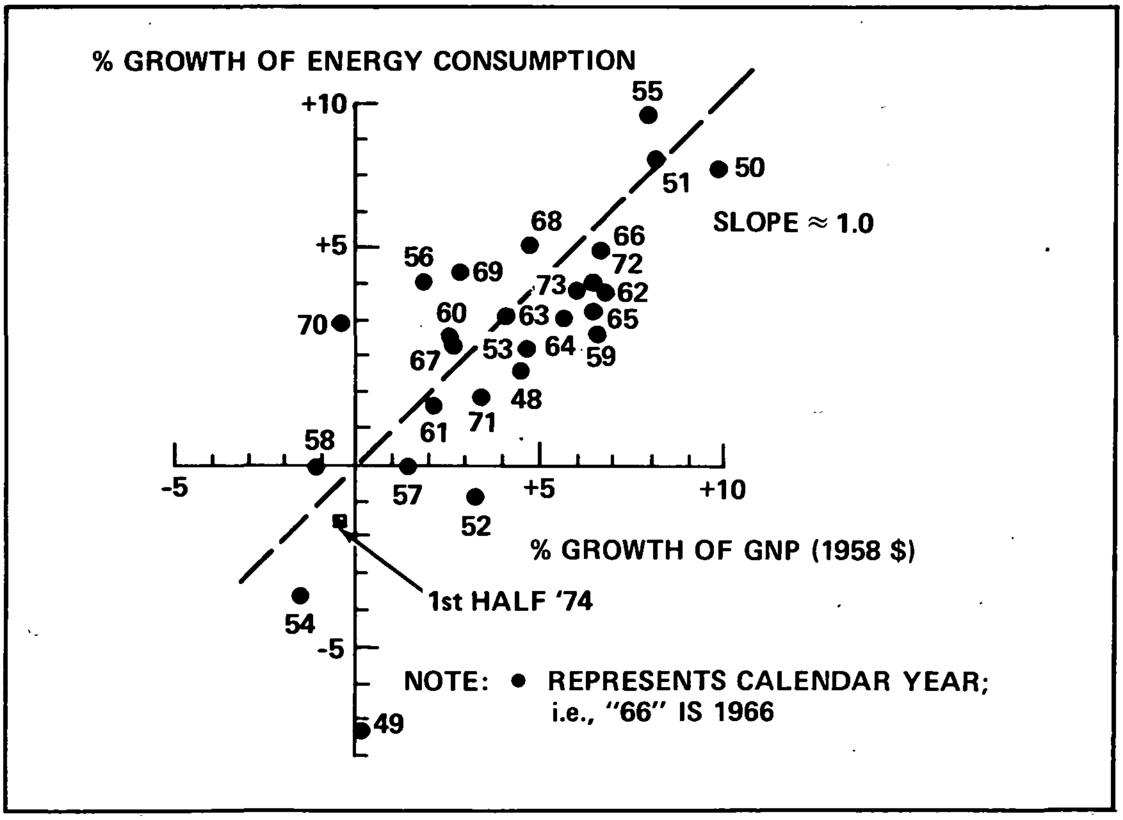


Figure 2. The Interdependence of Energy and Economic Growth (from Reference 3).

These are some of the elements of non-renewable resource trends that have caused the nation to seek an energy policy and strategy (or strategies) – an action still in process, and likely to be for some time because of the complexity of the economic, political, and institutional issues. The major elements of the evolving policy are likely to be (1) conservation of available resources; (2) broadened base of energy sources to include nuclear, solar, geothermal, etc., and the increase of supplies of known fuel through exploration and development; and (3) expanded research and development.

Population Growth

With only a few reversals due to famine or disease, the world's population has grown steadily since the agricultural revolution; the rate of growth has become exponential in the last 200 years. Estimates place the world population at the time of Christ at 200 million; by 1750 the number had grown to 800 million; by 1975, to 4 billion; and the year 2000 estimate is between 6 and 7 billion (based on constant fertility and no global disasters).

The population growth is, by and large, a regional or national issue (see Table 1). Although the world average rate of increase is 2.0%, the rates vary from 0.6% for the U.S. and Europe to 2.5 to 3.0% for the underdeveloped areas – Africa, Latin America, Southern Asia. Many nations perceive their population growth not as a problem, but as a means to ensure economic growth. But massive starvation is an ever-present threat in India, Bangladesh, sections of Africa, and other areas where food reserves and the margins between supply and demand are such that poor crops lead to severe food shortages.

For the U.S., the primary issues associated with population are the changing age distribution and the changing demography as urbanization increases. Growth in total

Table 1

Trends in Population Growth

Area	1973 Pop. (billions)	Annual Rate of Natural Increase (percent)	2000 Pop. (billions)	? Zero Population Growth Level after 2050 (billions)
U.S.	0.21	0.6	~0.3	<0.4
Developed Countries	1.12	0.8	~1.4	1.5-2
Underdeveloped Countries	2.74	2.5	~5.3	6.5-13
World	3.86	2.0	6-7	8-15

numbers is expected to be modest, from 210 million in 1975 to between 280 and 300 million in 2000. But because of the reduced birth rate and improved health care, the U.S. population is aging; it is projected that the age group over 45 will rise from about 24% in 1975 to 33% in 2000, and the age group 25 to 44 will increase from 22% to almost 30%. The implications are largely economic: shifts in demands for goods, services, and government expenditures for health care and social security. Society's values and priorities may be expected to shift also, because of the different values of different age groups and the observed persistence of values among these age groups as they mature.

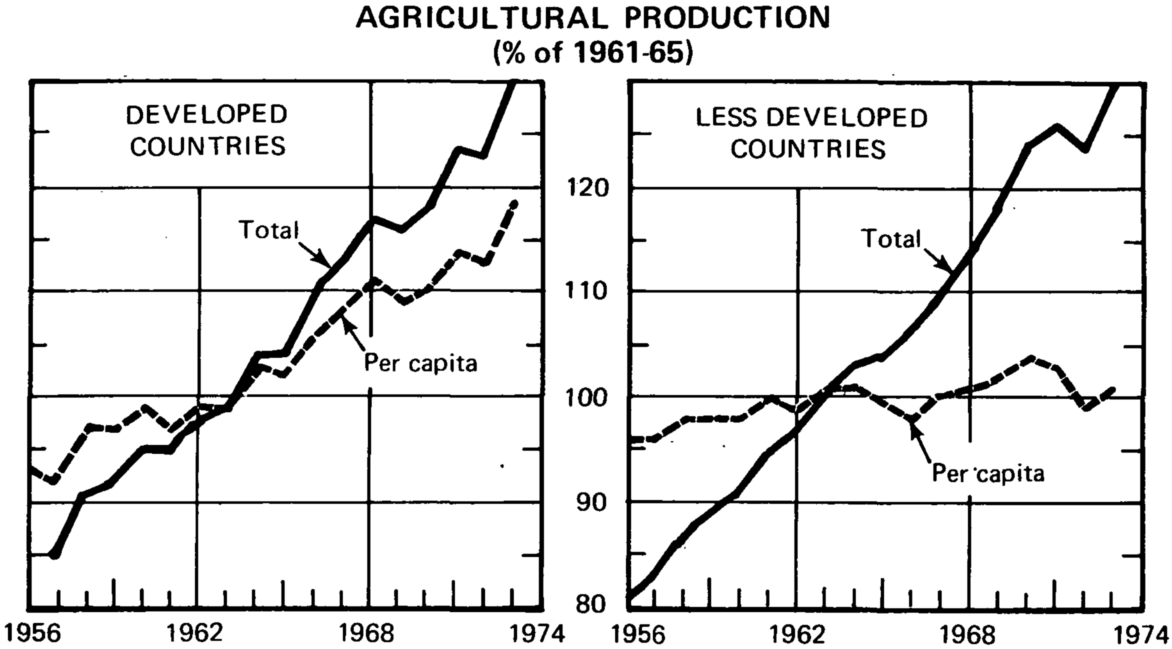
The growth of cities has been concomitant with population growth and reduced dependence on the land; people live in close urban proximity to take advantage of the economic opportunities and the exciting life styles made possible by the city. In developed nations, urbanization has taken the form of suburbanization, an effort of the more affluent to have the advantages of both country living and city life. By the year 2000, based on current projections, over 80% of the U.S. population will live in urban areas (compared to 70% in 1975) with current trends toward congestion, pollution, crime, and alienation of the individual expected to continue.

In spite of these trends, there appears to be no world consensus of solutions to the problems. Developed societies, which could accept some growth, tend to curb their growth, while many underdeveloped societies express the view that curbing their growth would deprive them of the opportunity to achieve affluence.

The World Food Situation

The availability of foods and the status of agriculture throughout the world are closely tied to the population trends. This is also a regional problem, but on a global scale the most striking fact has been the decrease in world grain reserves, which has fallen from 60 days in 1961 to about 20 days in 1974. The import-export distribution reveals that only North America is a major surplus-producing region; however, in the U.S. and elsewhere, reserves of idle cropland have been reduced in the period of 1961 to 1974, until they are essentially zero in the U.S. The "green revolution" of new strains of grain has stretched the reserves a few years, and now has been slowed by the limited availability of petroleum-based fertilizers. The margins are so small, and the inelasticity in demand so strong, that small changes in weather and other factors, including distribution, produce large fluctuations in the availability of food and at times, great potential for massive starvation and disease in many regions.

Food production throughout the world has basically kept pace with population growth; available calories per person have risen in the developed nations and remained essentially constant in developing countries (see Figure 3). Yet every year there are 75 million more mouths to feed. At this rate, food production will have to double by the year 2000 to maintain the same sub-marginal world levels as exist at present. Related problems focus on the need to improve and protect the world's grain supplies



DEVELOPED COUNTRIES: North America, Europe, U.S.S.R., Japan, Republic of South Africa, Australia, and New Zealand.

LESS DEVELOPED COUNTRIES: Latin America, Asia (except Japan and Communist Asia), and Africa (except South Africa).

Figure 3. World Agricultural Production (from Reference 4).

and distribution so that the impact of regional variations in production can be minimized, particularly in the developing nations.

Table 2 shows the population and cultivated land on each continent compared to the amount of potentially arable land outside the humid tropics. It appears that the principal population increases between 1965 and 1985 will occur in Asia, Africa, and South America. In Asia a small fraction of the land now cultivated lies in the humid tropics; hence, the total present cultivated area (470 million hectares) actually exceeds the area that is potentially cultivatable outside the humid tropics. In both Africa and South America, however, the potentially arable area can be increased several times. For all continents, the estimated population increase for the period 1965 to 1985 amounts to about 43%, whereas the potential increase in arable land outside the humid tropics is about 80%. Consequently, the world's food needs might be met until 1985 by significant increases in cultivatable land, with additional means probably being required thereafter. However, large amounts of investment capital, fertilizer, and agricultural knowledge would be required. All are in relatively short supply. In addition, within the definition of "cultivatable land", the most productive land, requiring least capital and effort, is already in use, with the remainder costing

Table 2

Comparison of Population and Arable Land, By Continents* (from Reference 5)

AREA	1965				1985	
	Population (billions)	Arable Land* (Hectares)		Arable Land per Person (Hectares/person)	Population (billions)	Arable Land per Person (Hectares/person)
		Cultivated	Potential			
Asia	1.86	470**	465	0.3	2.70	0.2
Africa	0.31	160	500	0.5	0.52	1.0
Europe	0.45	150	170	0.3	0.49	0.3
South America	0.20	80	370	0.4	0.39	0.9
North America	0.26	240	450	0.9	0.33	1.4
U.S.S.R.	0.24	230	350	1.0	0.30	1.2
Australia and New Zealand	0.01	20	120	1.4	0.03	4.8

*Not counting humid tropics

**Some humid tropic area is already under cultivation in Asia.

more and requiring more effort to achieve a worthwhile output. It would appear, therefore, that the need must be met from a combination of increased yield in presently cultivated areas and an increase in cultivated lands. The criticality of the situation also indicates the need for greater efficiency in managing the world's foods, including more accurate forecasting of production and factors such as water, weather, and climate.

The Environment

Increases in population, industrialization, and energy consumption have contaminated the physical environment to an extent that a strong environmental counter-movement has developed, with legislative bodies and other organizations trying to alleviate the problem. Local air pollution has been estimated to cause health damage affecting more than 50 million people at an annual cost of $6 billion in the U.S. alone. Some water supplies are contaminated with carcinogenic compounds. Toxic substances of all kinds, ranging from mercury to the polychlorinated hydrocarbons, have been found in the human food chain. Persistent pesticides such as DDT, which played a major role in health improvement by the control of insect-borne diseases, have been removed from the U.S. market. Solid wastes were produced in the U.S. at the rate of 50 million tons in 1920, and 170 million tons in 1970, and it is estimated that the figure will reach 350 million tons in 1990.

Population increase and the growth of society's aspirations and mobility have led to major incursions upon natural and wilderness areas, wildlife habitats, and agricultural lands. It has been estimated that an additional 20 million acres will be similarly utilized in the U.S. by the year 2000 – an area equal to New Hampshire, Vermont, Massachusetts and Rhode Island. Strip mining, the most economical means of mineral acquisition, is another potential major encroachment. Coal strip mining alone may consume up to 90,000 acres by 1990 and 200,000 by the year 2000. A major problem in the western coal lands, where strip mining is most effective, is the lack of water necessary for reclamation; there is a notable geographic "mismatch" between coal resources and water resources in the U.S.

Globally, waterways have been contaminated by untreated domestic sewage, industrial effluents, and chemical fertilizer from agricultural lands – all of which will increase in proportion to population and the growing affluence of that population.

The atmospheric ozone layer, which protects terrestrial life from solar ultraviolet radiation, may be adversely influenced by highflying aircraft, aerosols, and organic chemicals inherent to industrial processes. Small particles are injected into the atmosphere from the burning of fossil fuels, the incidence of carbon dioxide has increased by about 2% since 1910, and carbon monoxide now is increasing by about 2% per year. The effects are not well understood, but the climate seems to be changing in ways that could accelerate the food problem.

The Accumulation and Use of Scientific and Technical Knowledge

The history of scientific and technological growth in the centuries since Galileo has been described by some individuals as the supreme triumph of human history. Much of our culture is based on this accumulated knowledge and technology. Despite challenges to the role of technology in society, and the recognition that technology can be used for good or harm, there is no reason to expect a slowing of this trend, because the aspirations of developing nations depend upon technology. Control and direction of the growth can be expected. As the use of this knowledge grows, persons trained in the discipline become a larger part of the population (Table 3).

Table 3

Growth in Scientific and Engineering Employment in the United States (from Reference 6)

Year	Scientists	% of Pop.	Engineers	% of Pop.	Active Population (millions)
1930	96,000	0.09	220,000	0.44	50
1940	90,000	0.16	300,000	0.55	55
1950	160,000	0.27	500,000	0.83	60
1960	320,000	0.50	1,200,000	1.20	65
1970	730,000	1.00	2,600,000	1.60	75

The innate human drive to understand and control our external environment has had a profound influence on all aspects of life – political, cultural and economic. For many centuries this drive proceeded in a sporadic, chaotic fashion, sometimes motivated by the economic necessity of predicting the time of the flooding of the Nile and sometimes by pure curiosity such as why two bits of fluff are attracted when rubbed on a piece of amber. Whatever the motivation, the net effect has been an ever increasing knowledge of the nature of our environment and our ability to affect it. For the past 200 years, since Bacon originally advanced the thesis that the steady expansion of human knowledge and the systematic application of that knowledge to the needs of humanity would materially benefit the human condition, society has accumulated knowledge, the technical skills, and the hardware to put that knowledge to work at a steadily accelerating pace. It took almost 200 years of systematic study of the nature of electricity before Faraday finally understood how to put it to work for the benefit of humanity. It took another 50 years to develop the electrical technology that was needed to study and understand the nucleus and release for use the new and even more powerful nuclear energy. It required only about 25 years to develop the skills and hardware to put nuclear energy to use.

Until very recently there was general agreement with Bacon's thesis that the advances of science and technology had indeed improved the human condition. Humans could enjoy a better and more stable diet, live more comfortably in centrally heated and air conditioned homes, travel faster in greater comfort, be less subject to disease, and savor an enormous diversity of cultural activities. In the past decade, however, it has become clear that we cannot haphazardly deploy a major new technology without the most careful examination of its interaction with and long-term influence upon the environment and the human condition. This realization does not mean, however, that science and technology are inherently bad, or we will not need as many scientists and engineers in the future. On the contrary, the need to understand the impact of a new technology on the environment or to produce the resources needed by the world's burgeoning population will create a greater demand for understanding the forces that control the environment and for developing the skills and technology systems required to meet the needs of humanity in the decades ahead.

Today the transfer of experience and knowledge from one situation to a completely different one is more commonplace. The computer evolved from work carried out some 40 years before; the laser evolved from work performed 30 years earlier. This use of both theory and basic research, which has been successful in the physical and chemical sciences, is now expanding into the social and behavioral sciences and the field of economics.

This new capability is made possible by developments that may be applied to problems of organized complexity: developments in information theory, cybernetics, decision theory, game theory, utility theory, probability theory, and stochastic processes. From these developments have come specific techniques such as linear programming, statistical decision theory, Monte Carlo randomizing, and minimax solution – all useful in making decisions when many variables are involved. All this is made possible by large-scale computers and will be used extensively over the next 25 years.

The Communications Revolution

A relatively recent phenomenon that has had an extensive and multifaceted impact on the world, and is widely predicted to have a more profound impact in the future, is electronic communications. These methods of communication have grown (Table 4) from local, single message telegraph services established by Western Union in 1851, to present-day satellite-borne, global links carrying 5,000 simultaneous two-way conversations, or 12 TV channels. The scope of the technological capabilities is only partially illustrated by Figure 4, the global communications satellite system. In 1964, nineteen nations formed the International Telecommunications Satellite Organization (Intelsat), which by 1975 had grown to include 89 nations, with 66 having direct access through their own ground stations. Intelsat's investments in satellites, boosters and related services has passed the one billion dollar mark, and the participating nations, including the People's Republic of China and the Soviet Union, have invested about 500 million dollars in Earth terminals.

Table 4

Electronic Communications
(Dates of Initiation of
Commercial Services)

Type	Year
Wire Telegraphy	
Local	1851
Transcontinental	1861
Transatlantic	1866
Wire Telephony	
Local	1877
Transcontinental	1915
Transatlantic	1956
Radio Telegraphy	
Local	1900-1915
Transatlantic	1910
Radio Telephony	
Local	1929
Transatlantic	1927
Radio Broadcast	1921
TV Broadcast	1941
CATV	1949
Satellite	1965

This rapid growth in capability is only an indication, however, of the potential directions in which communications technology may have influenced our lives. By creating first a "wired nation," then a "wired world," incorporating broadband networks capable of providing almost unlimited communications into our homes and offices, a great range of changes, such as the following, may be introduced into our educational, political, entertainment, travel, and other social systems (see Reference 7). For example, we may soon:

- Find the videophone in common use.
- Select from a great variety of entertainment and informational materials.
- Shop, bank, pay bills, and trade stocks by pushbutton or voice direction.
- Receive facsimile printouts of newspapers, mail, and other communications.
- Have the world's knowledge, in microfilmed libraries, at our fingertips.
- Be polled, vote, participate in community and national activities, by wire.
- Have around-the-clock police and fire protection through automatic surveillance devices.
- Watch news events as they occur, wherever they occur.

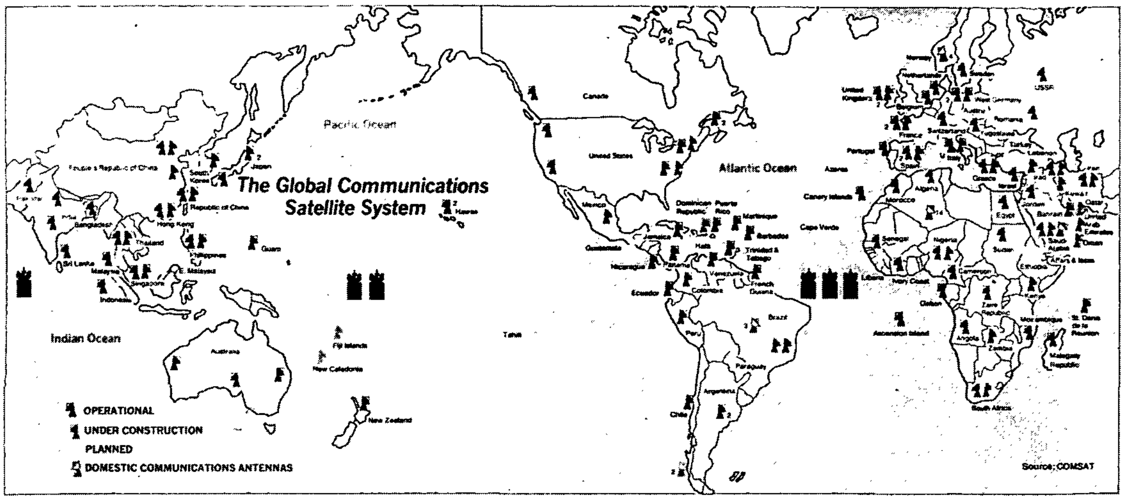


Figure 4

At issue in such developments are the questions such as economics, content of communications, their control, individual privacy, etc.

Disparity Between Wealthy and Poor Nations

It has been argued that one of the greatest forces for international conflict today is an inequitable allocation of accumulated wealth and an inequitable distribution of potential wealth and resources. While inequity in the world is clearly not new, the gap between the rich and poor nations is widening. Seventy percent of the world's population lives in lesser developed countries, and this fraction has been increasing over the past twenty years, see Table 5. At the same time, the concentration of wealth is becoming increasingly inequitable. Per capita incomes in concentration of wealth is becoming increasingly inequitable. Per capita incomes in the developed world grew 3.9 percent in 1960 to 1968 period, but only grew at 2.7 percent in the less developed countries. While real economic growth (measured in terms of GNP growth) may be increasing at greater annual rates in some of the less developed countries, population growth diminishes these advantages. Also, the disparity in standards of living indicates that, even if substantially higher rates of economic growth were sustained for lengthy periods of time (a situation most economists believe to be impossible), it would require centuries to narrow the gap.

This widening gap is becoming a source of international conflict among nations. Less developed countries are beginning to resort to group actions such as tacit and covert terrorism, resource cartels, and political blackmail to achieve economic and political objectives. The recent economic and political success of the OPEC cartel is likely to encourage similar activities by other nations.

Table 5

GNP Per Capita and Population Growth Rates
(from Reference 8)

FOURTH WORLD COUNTRY	GNP/CAPITA (U.S. DOLLARS) 1972	POPULATION GROWTH RATE	
		1960-72	1965-72
Bangladesh	70	2.6	2.5
Central African Republic	160	2.2	2.2
Chad	80	1.8	1.8
Ethiopia	80	2.2	2.4
Gambia	140	2.0	1.9
India	110	2.3	2.3
Mali	80	2.1	2.1
Mauritania	180	1.9	1.9
Niger	90	2.9	2.8
Pakistan	130	3.2	4.1
Senegal	260	2.1	2.2
Upper Volta	70	2.1	2.1
Sri Lanka	110	2.4	2.3
DEVELOPED COUNTRY (10 top countries in GNP/capita)			
United States	5590	1.2	1.0
Sweden	4480	0.7	0.7
Canada	4440	1.7	1.5
Switzerland	3940	1.2	1.0
Denmark	3670	0.7	0.7
France	3620	1.0	0.8
West Germany	3390	0.9	0.6
Norway	3340	0.8	0.8
Belgium	3210	0.5	0.8
Australia	2980	2.0	1.9

This is not a new problem, but it is viewed with increasing concern because the mechanisms of conflict are becoming so powerful. Many pressures aggravate the situation, including:

- The technological advances in weaponry and the proliferation of nuclear weapons and nuclear materials among the nations of the world increase the likelihood of nuclear blackmail or nuclear war.

- The proliferation of communications and increasing contact between rich and poor nations has increased the awareness of this widening gap; before the advent of widespread communications among countries the discrepancies in standards of living were only readily apparent through international travel, limited to an extremely small fraction of the population. Such increasing awareness contributes to the level of expectation, frustration, and eventually, militancy.

- The failure of traditional economic development approaches to stem the widening gap has generated frustration and encouraged new approaches to economic wealth, regardless of how radical, militant, and threatening they may be.
- The realization by many of the less developed (but resource rich) nations that they have played an essential role in the economic development and concentration of wealth in other nations (perhaps at the price of their own development) has generated a sense of exploitation and a desire for expropriation.

Continuing Inflation

For the first time in American history, consumer prices as well as wholesale prices have experienced sustained periods of rapid increase during peacetime. In 1974, consumer prices increased 12.2%, the biggest annual increase since 1946 when prices increased 18.2% following the abolition of World War II price controls. There have been five major inflationary periods in the history of the United States: the Revolutionary War inflation, the War of 1812 inflation, the Civil War inflation, the World War I inflation, and the inflationary period since World War II. The first four of these inflationary periods were generally caused by the same short-lived original phenomenon; that is, government deficit spending to finance the war effort. Contrary to the current experience, the previous four inflationary periods were brought to a close by an immediate return to a balanced budget, a substantial decrease in total government spending, and explicit anti-inflationary actions. The post-World War II inflation, contrary to the others, has persisted. Quite clearly, something new is happening.

An examination of historical trends shows how atypical the current situation is. Figure 5 presents the wholesale and consumer price index for about the past 100 years. It has been only recently, beginning around the end of the 1940s, that both the Wholesale Price Index and the Consumer Price Index have maintained a rather consistent upward trend.

Why is this period so different? Inflation is remaining impervious to the traditional remedies (although one school of thought argues that the traditional remedies have not actually been effective). High inflation has continued unabated for such an extended period of time that significant unemployment is occurring because of the impact of the reduction in disposable and discretionary income.

The results of this inflation have been widespread in the form of erosion of personal income, unemployment, reduction in the gross national product, curtailment of economic growth, balance of payments deficits, and a host of other related problems. Clearly the continuation of this trend will affect the ability of this nation to respond to its own needs, and both the ability and will of the nation to respond to global needs.

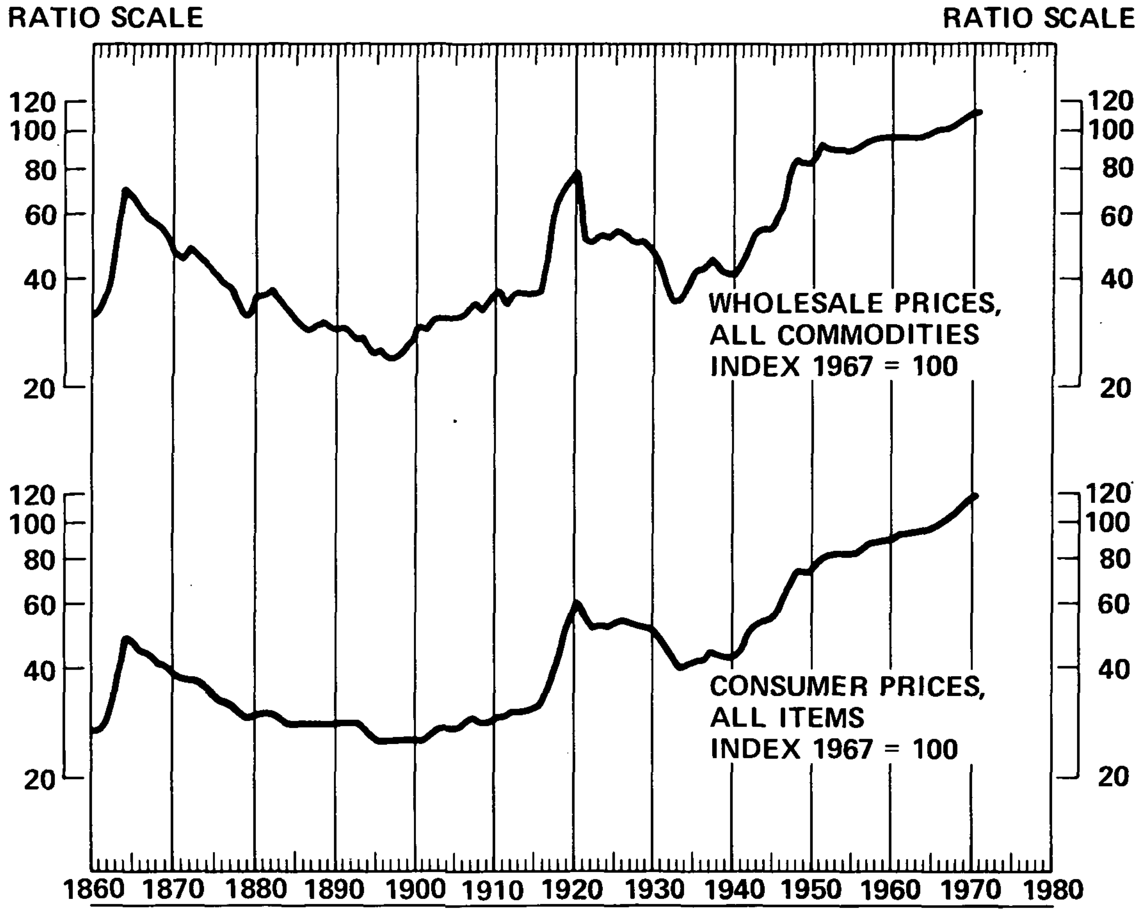


Figure 5. Historical Growth of Inflation (from Reference 9).

Trends in National Interdependency and Polarization

With the growth in population and associated aspirations, and with the growth in the knowledge of our neighbors through better communications, the interdependency of human beings, on both a local and a global basis, is increasing. This is noted in other trends such as energy sources. This growth in interdependency extends not only to things, but to services and the knowledge of others as well.

However, while this trend toward ever greater interdependency has been taking place, a counter trend has been prominent in recent times on a local and a global basis, among cultures, ethnic groups, individuals, and nations. In spite of efforts to develop greater tolerance, there has been a tendency in recent times to polarize, to tighten up into enclaves of thinking and culture, and to "go it alone" without benefits of, or in opposition to, peer groups. The irony of this is that the people of the Earth must act collectively to cope with their common human problems. Both large and small nations are dependent upon and vulnerable to events around this Earth. We are in instant communication with one another, and people and ideas travel swiftly. Multinational corporations, societies of the art forms, financial networks, and institutions and activities of every kind are causing greater intermingling and are denying the opportunity for isolation.

At the same time, undoubtedly due to reactions associated with the demise of colonialism, but also perhaps to a reaction to our growing interdependency and concern over dependence on others for vital necessities, many age, ethnic, sex, cultural, or national heritage groups tend to voice some degree of a separatism and independence from fellow human beings and counter groups. The extent of this separatism ranges from the counter-culture groups in considerable evidence in this country during the late 1960s to the revolutionary actions, such as those taking place in Northern Ireland, which continue to dominate the domestic policies of many countries.

The conflict of these two trends is expected to persist and to have consequences to the societal environment of the next 25 years, but the dominance of the interdependence trend is inescapable.

Personal and National Security

There is no expectation that conditions will be such in the next 25 years that the security of nations, segments of society, and individuals will lose their historical high priorities.

The importance of security is illustrated by the portion of the Gross National Product that a nation devotes to defense expenditures, and to law enforcement activities. Since 1961, military expenditures around the world have increased about 50% in terms of 1975 dollars. In the U.S. and western Europe, such expenditures have declined in relationship to the GNP over that period, whereas in the Soviet Union and the developing nations, the percentage has increased. In the Near East the percentage has doubled in the last decade.

The U.S. decline may be explained partially by a sense of security in the fact that there have been no recent devastating major conflicts on its territory. On the other hand, developing nations not only aspire to the affluence of the developed nations, but also covet the strength they believe will afford them advantages relative to their neighbors.

More dramatic is the increase in threats to personal security. Some streets in urbanized communities are not safe at night, whereas 30 years ago such conditions were generally unknown. There does seem to be a suggested correlation between threats to personal safety and:

- Increasing population, plus a trend toward a more materialistic culture with a corresponding decline in the regard for human life and suffering

- Increased experiences through the considerable exposure by improved communication capabilities to all conceivable forms of violence, which tend to dull the sensibilities of individuals to the sufferings of others

The Attitude of Individuals Toward Challenge

Many individuals in the more industrialized, developed nations experience disillusionment and frustration with the tempo and complexities of life. Most individuals need some form of challenge, and many who are not personally experiencing such challenges seek them vicariously as spectators, and welcome such spectacles with an aura of high adventure, invention, daring, and risk. This is clearly evident in the statistically significant data on the visual appeal of motion pictures and television. As our society becomes more and more concerned with its physical needs, it tends to become less challenging and innovative.

The Quest for an Understanding of the Origin and Future of Human Beings, Their Earth, and Place in the Universe

The most profound questions which have occupied the minds of thinking people pertain to our origins and future. Since the beginnings of our existence on earth, human beings have gazed at the heavens in the manner of a child with its nose pressed against a glass window – able to look, but unable to enter.

From what has been observed and studied, ranging from transits of Venus recorded on Babylonian tablets, to the detailed structure of distant galaxies observed through the 500 centimeter Mount Palomar telescope, we are now beginning to acquire a cosmic perspective of thinking. The overwhelming questions include: How life may have originated from inanimate matter on the surface of the Earth, how Earth is an integral part of the solar system and, at the same time, unique among the planets, how our sun is only one of the trillions of other stars in the universe, and how the entire Universe may have had its beginnings in a gigantic fireball called the "Big Bang" some 10 to 20 billion years ago.

In the past our thinking on this subject did not necessarily evolve at the same pace as our capability to look farther into space. It was the extraordinary brilliance of a few minds like Copernicus, Newton, and Einstein that salvaged us from the dogma that the essence of things must forever remain hidden. Today, with the foundations of modern science firmly established, as we push the frontiers of observation to the edges of the Universe, we are also pushing back the limits of our ignorance. Modern scientists, equipped with extraordinary technological tools for observation and theory, are fast converging on a story of the origin of human beings which extends back not only to the "primordial soup" on the surface of the Earth, but to the original "Big Bang." The opportunities before us to continue this trend in understanding over the next 25 years portend an enormous impact on our thinking, our attitudes, and our destiny.

To us it was significant that importance of this challenge was expressed not so much by scientists, but by individuals quite outside the field of science and engineering.

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CHAPTER 5

POTENTIAL FUTURE SPACE ACTIVITIES

INTRODUCTION

The purpose of the phase of the study summarized in the previous chapter was to examine those aspects of probable trends which will influence the contributions of space activities to the needs of society. Since understanding a problem is prerequisite to formulation of a solution, the Study Group tended to focus on problems and to highlight the factors which will tend to cause them. As we have listed them, we recognize that they appear to cast a cloud of great foreboding. This, however, is neither our intent nor our opinion. It is a necessary step toward understanding those activities which must be undertaken to stem or reverse those forces which apparently would, if left unchanged, have major adverse effects on the well-being of this nation and of the world. All of those who spoke with us, whether on physical needs or the need to challenge the mind, emphasized the requirement for the space program to address the needs of people. Some were skeptical as to whether or not this requirement could really be fulfilled, and whether or not the space program could "pay its way" in today's society. Others were more optimistic on the potential of space flight and the benefits which might be derived from it. But all, skeptics and optimists, agreed that the program must not only respond to human requirements but that the public which is being called upon to support it must perceive that response as beneficial.

In accordance to the objectives set for the study, and guided by the thoughtful insights of our advisors, we accepted as basic to our task the need to establish clear links between space objectives and national challenges, and to use those links as tests for the completeness of our work and the value of the future space flight potentials which we identified. To understand better how space can respond to the problems and possibilities which the trends imply, the Study Group organized space activities into twelve major themes and defined specific objectives within these themes (see Table 6).

The first seven themes deal primarily with the Earth, and the last five with extraterrestrial questions. Within each theme the objectives were selected on the basis of two criteria: (1) whether accomplishment of the objective would constitute a significant response to the major thrust of the theme; and (2) whether space activities could make an important contribution to the accomplishment of the objective.

In accordance with one of the study guidelines, the period of the 1980s is highlighted. Systems* capable of pursuing these objectives are listed in Table 7 and

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*A "system" is defined as spacecraft or ground-based information activity, or a combination of the two, or necessary laboratory work. A single system may involve several space flights.

Table 6

Future Space Objectives – 1980 to 2000

EARTH ORIENTED ACTIVITIES RESPONSIVE TO BASIC HUMAN NEEDS

THEME 01: PRODUCTION AND MANAGEMENT OF FOOD AND FORESTRY RESOURCES
Objective 011 – Global Crop Production Forecasting
Objective 012 – Water Availability Forecasting
Objective 013 – Land Use and Environmental Assessment
Objective 014 – Living Marine Resource Assessment
Objective 015 – Timber Inventory
Objective 016 – Rangeland Assessment

THEME 02: PREDICTION AND PROTECTION OF THE ENVIRONMENT
Objective 021 – Large-Scale Weather Forecasting
Objective 022 – Weather Modification Experiments Support
Objective 023 – Climate Prediction
Objective 024 – Stratospheric Changes and Effects
Objective 025 – Water Quality Monitoring
Objective 026 – Global Marine Weather Forecasting

THEME 03: PROTECTION OF LIFE AND PROPERTY
Objective 031 – Local Weather and Severe Storm Forecasting
Objective 032 – Tropospheric Pollutants Monitoring
Objective 033 – Hazard Forecasting from *In-Situ* Measurements
Objective 034 – Communication-Navigation Capability
Objective 035 – Earthquake Prediction
Objective 036 – Control of Harmful Insects

THEME 04: ENERGY AND MINERAL EXPLORATION
Objective 041 – Solar-Power Stations in Space
Objective 042 – Power Relay via Satellites
Objective 043 – Hazardous Waste Disposal in Space
Objective 044 – World Geologic Atlas

THEME 05: TRANSFER OF INFORMATION
Objective 051 – Domestic Communications
Objective 052 – Intercontinental Communications
Objective 053 – Personal Communications

THEME 06: USE OF ENVIRONMENT OF SPACE FOR SCIENTIFIC AND COMMERCIAL PURPOSES
Objective 061 – Basic Physics and Chemistry
Objective 062 – Materials Science
Objective 063 – Commercial Inorganic Processing
Objective 064 – Biological Materials Research and Application
Objective 065 – Effects of Gravity on Terrestrial Life
Objective 066 – Living and Working in Space
Objective 067 – Physiology and Disease Processes

THEME 07: EARTH SCIENCE
Objective 071 – Earth's Magnetic Field
Objective 072 – Crustal Dynamics
Objective 073 – Ocean Interior and Dynamics
Objective 074 – Dynamics and Energetics of Lower Atmosphere
Objective 075 – Structure, Chemistry, and Dynamics of the Stratosphere Mesosphere
Objective 076 – Ionosphere-Magnetosphere Coupling

EXTRATERRESTRIAL ACTIVITIES RESPONSIVE TO INTELLECTUAL HUMAN NEEDS

THEME 08: THE NATURE OF THE UNIVERSE
Objective 081 – How did the Universe Begin?
Objective 082 – How do Galaxies Form and Evolve?
Objective 083 – What are Quasars?
Objective 084 – Will the Universe Expand Forever?
Objective 085 – What is the Nature of Gravity?

THEME 09: THE ORIGINS AND FATE OF MATTER
Objective 091 – What is the Nature of Stellar Explosions?
Objective 092 – What is the Nature of Black Holes?
Objective 093 – Where and How Were Elements Formed?
Objective 094 – What is the Nature of Cosmic Rays?

THEME 10: THE LIFE CYCLE OF THE SUN AND STARS
Objective 101 – What are the Composition and Dynamics of Interstellar Matter?
Objective 102 – Why and How Does Interstellar Dust Condense Into Stars and Planets?
Objective 103 – What are the Nature and Cause of Solar Activity?
Objective 104 – Corona and Interplanetary Plasma
Objective 105 – What is the Ultimate Fate of the Sun?

THEME 11: EVOLUTION OF THE SOLAR SYSTEM
Objective 111 – What Process Occurred During Formation of the Solar System?
Objective 112 – How do Planets, Large Satellites, and Their Atmospheres Evolve?
Objective 113 – How Can Atmospheric Dynamics be Quantified?
Objective 114 – What are the Origin and History of Magnetic Fields?

THEME 12: ORIGINS AND FUTURE OF LIFE
Objective 121 – How Did Life on Earth Originate?
Objective 122 – Is There Extraterrestrial Life in the Solar System?
Objective 123 – What Organic Chemistry Occurs in the the Universe?
Objective 124 – Do Other Stars Have Planets?
Objective 125 – Can We Detect Extraterrestrial Intelligent Life?

Table 7

Candidate Systems

SERIES 1000

1001. Global Positioning and Communicating System – Development
1002. Global Positioning and Communicating System – Operational
1003. *Expanded Coverage Comm. Navigation System* – Development
1004. Expanded Coverage Comm. Navigation System – Operational
1005. Advanced Techniques Comm. Navigation System – Development
1006. Advanced Techniques Comm. Navigation System – Operational
1007. Solar Power Technology
1008. Solar Power Space Test Activity
1009. Solar Power Prototype – Development
1010. Solar Power System – Operational
1011. Power Relay Technology – Development
1012. Power Relay Space Testing
1013. Power Relay Prototype – Development
1014. Hazard Waste System – Development
1015. Hazard Waste System – Operational
1016. (Intentionally Left Blank)
1017. (Intentionally Left Blank)
1018. Domestic Communications System – Development
1019. Domestic Communications System – Operational
1020. Multi-Service Domestic Communications System – Development
1021. Multi-Service Domestic Communications System – Operational
1022. International Communications System – Development
1023. International Communications System – Operational
1024. Multi-Service International Communications System – Development
1025. Multi-Service International Communications System – Operational
1026. Personal Communications System – Development
1027. Personal Communications System – Operational
1028. "Short Term" Physical Chemical Research – Crew Operated
1029. "Long-Term" Physical Chemical Research – Crew Operated
1030. "Short-Term" Low-g Material Science Research – Crew Operated
1031. "Long-Term" Low-g Material Science Research – Crew Operated
1032. *Commercial Processing – Crew Operated*
1033. "Short-Term" Biological Materials Research – Crew Operated
1034. "Long-Term" Biological Materials Research – Crew Operated
1035. Preliminary Effects of Gravity on Life – Crew Operated
1036. Effects of Gravity on Life – Crew Operated
1037. Human Performance in Space – Development
1038. Human Performance in Space – Operational
1039. Preliminary Disease Processes Research – Crew Operated
1040. Disease Processes Research – Crew Operated
1041. Magnetic Field Change Satellite
1042. Magnetic Field Survey
1043. Geodetic Satellites
1044. Gravitational Satellites
1045. Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) – Crew Operated
1046. Atmospheric Neutral and Charged Particle Research
1047. Electrodynamic Explorer
1048. Wide Field X-Ray and Gamma Ray
1049. 1m UV Telescope
1050. 2.4m Space Telescope (LST)
1051. 5-6 m Space Telescope
1052. Small Submillimeter Receiver
1053. Infrared Interferometer
1054. Large Cryogenic IR Telescope
1055. Microwave LBI
1056. High Energy Astrophysics Spacelab Cluster
1057. Large Area Gamma-Ray Detector
1058. Low Energy Gamma Explorers
1059. Large X-Ray Telescope
1060. 1.2 Meter X-Ray Telescope
1061. Heavy Cosmic Ray Detector
1062. Relativity Experiments in Earth Orbit with Freely Spinning Gyroscope
1063. Gravity Wave Detector
1064. Eötvös Effect Experiment
1065. Stable Clock/Gyro in Solar Orbit
1066. Mercury Orbiter (W/Penetrometers)
1067. Interplanetary Near-Sun Probe
1068. 700 Kilogram X-Ray Monitor
1069. Solar System Escape Spacecraft
1070. 10,000 Kg Solar Observatories
1071. Observatory in Solar Polar Orbit
1072. Large Ambient IR Telescope
1073. Submillimeter Telescope
1074. Low Frequencies LBI
1075. Spacelab Solar Telescope Cluster
1076. Solar Monitor
1077. *1600 Kg Solar Observatory*
1078. Mercury Sample Return
1079. Venus Surface Sample Return
1080. Mars Surface Sample Return
1081. Jupiter Atmospheric Probes
1082. Saturn Atmospheric Probes
1083. Titan Orbiter W/Penetrometer

Table 7 (cont'd)

1084. Uranus Atmospheric Probe
1085. Asteroid Sample Return
1086. Comet Sample Return
1087. Venus Orbiter Imaging Radar W/Penetrometers
1088. Venus Lander
1089. Lunar Sample Return (Highlands)
1090. Mars Polar Orbiter (W/Penetrometers)
1091. Jupiter Orbiters Spinning/3 Axis
1092. Titan Lander
1093. Uranus Orbiter
1094. Asteroid Rendezvous W/Penetrometer Plus Laser
1095. Mars Lander/Rover
1096. Saturn Orbiter
1097. Neptune Orbiter
1098. Large Scale Microwave Telescope
1099. 200-1000 A UV Telescope
1100. 400 Kg UV Telescope Free Flyer
1101. Wide Field UV Survey
1102. Very Wide Field Optical Telescope
1103. Cryogenic IR Survey Satellite
1104. Lunar Polar Orbiter
1105. Lunar Orbiter W/Penetrometers
1106. Lunar Rover Unmanned
1107. Jupiter-Saturn Flyby
1108. Uranus Flyby
1109. Neptune Flyby
1110. Comet Flyby/Fly-Through
1111. Comet Rendezvous
1112. 4 Person Near Earth Orbit Space Station*
1113. 12 Person Near Earth Orbit Space Station*
1114. 12 Person Geosynch Space Station*
1115. 12 Person Lunar Base*
1116. Crew Operated Flight To Mars*
1117. Industrial Space Facility*

*Elements of many themes as discussed in Chapters 5, 6, and 9.

SERIES 2000

2001. High Resolution Visible-IR System – Development
2002. High Resolution Visible-IR System – Operational
2003. Very High Resolution Visible-IR System – Development
2004. Very High Resolution Visible-IR System – Operational
2005. All Weather Survey System – Development
2006. All Weather Survey System – Operational
2007. Long Wavelength Microwave System – Development
2008. Long Wavelength Microwave System – Operational
2009. High Resolution Long Wavelength Microwave System – Development
2010. High Resolution Long Wavelength Microwave System – Operational
2011. Weather Survey System I – Development
2012. Weather Survey System I – Operational
2013. Passive-Active Sensors, Large Scale Weather Survey System – Development
2014. Passive-Active Sensors, Large Scale Weather Survey System – Operational
2015. Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development
2016. Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational
2017. Earth Energy Budget Monitoring System – Development
2018. Earth Energy Budget Measuring System – Operational
2019. Advanced Earth Energy Budget Monitoring System – Development
2020. Advanced Earth Energy Budget Monitoring System – Operational
2021. Air Pollution Technology Satellite – Development
2022. Stratospheric Monitoring System – Development
2023. Stratospheric Monitoring System – Operational
2024. Stratospheric Constituents Monitoring System – Development
2025. Stratospheric Constituents Monitoring System – Operational
2026. Sea Survey Technology Satellite
2027. Sea Survey System – Development
2028. Sea Survey System – Operational
2029. High Resolution Sea Survey System – Development
2030. High Resolution Sea Survey System – Operational
2031. VISSR Atmospheric Sounder System – Development
2032. VISSR Atmospheric Sounder System – Operational
2033. Storm Satellite Survey System – Development
2034. Storm Satellite Survey System – Operational
2035. Synchronous Earth Observatory Survey System – Development
2036. Synchronous Earth Observatory Survey System – Operational
2037. Global Tropospheric Monitoring System – Development
2038. Global Tropospheric Monitoring System – Operational
2039. Regional Tropospheric Monitoring System – Development
2040. Regional Tropospheric Monitoring System – Operational
2041. Earthquake Prediction System – Development
2042. Earthquake Prediction System – Operational

Table 7 (cont'd)

SERIES 3000

3001. Global Wheat Prediction System – Development
3002. Global Wheat Prediction System – Operational
3003. Global All Crop Prediction System – Development
3004. Global All Crop Prediction System – Operational
3005. All Weather Global All Crop Prediction System – Development
3006. All Weather Global All Crop Prediction System – Operational
3007. Water Resource System I – Development
3008. Water Resource System I – Operational
3009. Watershed Runoff Forecast System – Development
3010. Watershed Runoff Forecast System – Operational
3011. Regional Water Balance Forecast System – Development
3012. Regional Water Balance Forecast System – Operational
3013. Surface Cover Change Detection System – Development
3014. Surface Cover Change Detection System – Operational
3015. Critical Environmental Area Monitoring System – Development
3016. Critical Environmental Area Monitoring System – Operational
3017. Land Capability System – Development
3018. Land Capability System – Operational
3019. Living Marine Resources System – Development
3020. Living Marine Resources System – Operational
3021. Broad Area Timber Inventory System – Development
3022. Broad Area Timber Inventory System – Operational
3023. Specific Area Timber Inventory System – Development
3024. Specific Area Timber Inventory System – Operational
3025. Range Forage Status System – Development
3026. Range Forage Status System – Operational
3027. Range Forage Prediction System – Development
3028. Range Forage Prediction System – Operational
3029. All Weather Range Forage System – Development
3030. All Weather Range Forage System – Operational
3031. Global Atmospheric Research Program System – Development
3032. Global Atmospheric Research Program System – Operational
3033. Post-GARP System – Development
3034. Post-GARP System – Operational
3035. Advanced Techniques Weather System – Development
3036. Advanced Techniques Weather System – Operational
3037. Weather Modification Experiments Monitoring System
3038. Climate Parametric Systems Study – Development
3039. Climate Parametric Systems Study – Operational
3040. Climate Forecasting System – Development
3041. Climate Forecasting System – Operational
3042. Stratospheric Parameter Experimental System – Development
3043. Preliminary Stratospheric Prediction System – Development
3044. Preliminary Stratospheric Prediction System – Operational
3045. "3 Dimensional" Stratospheric Prediction System – Development
3046. "3 Dimensional" Stratospheric Prediction System – Operational
3047. Water Quality Monitoring System – Development
3048. Water Quality Monitoring System – Operational
3049. Marine Parameter Experimental System – Development
3050. Marine Forecasting System – Development
3051. Marine Forecasting System – Operational
3052. Extended Parameter Marine Forecasting System – Development
3053. Extended Parameter Marine Forecasting System – Operational
3054. Cyclonic Scale Severe Weather Prediction System – Development
3055. Cyclonic Scale Severe Weather Prediction System – Operational
3056. Thunderstorm Scale Severe Weather Prediction System – Development
3057. Thunderstorm Scale Severe Weather Prediction System – Operational
3058. Day-Night Severe Storm Prediction – Development
3059. Day-Night Severe Storm Prediction – Operational
3060. Tropospheric Parameter Experimental System
3061. Global Air Pollution Analysis System – Development
3062. Global Air Pollution Analysis System – Operational
3063. Regional Air Pollution Prediction System – Development
3064. Regional Air Pollution Prediction System – Operational
3065. Hazard Warning System – Development
3066. Hazard Warning System – Operational
3067. Extended Hazard Warning System – Development
3068. Extended Hazard Warning System – Operational
3069. Disease Vectors System – Development
3070. Disease Vectors System – Operational
3071. Geological Mapping System – Development
3072. Geological Mapping System – Operational

SERIES 4000

4001. Earthquake Parameters – Development
4002. Very Long Baseline Interferometry
4003. Oceanographic Research
4004. Low Atmosphere Research
4005. Strato/Mesosphere Research
4006. Synthesis of Living Matter in Labs
4007. Earth Fossil and Rock Analysis
4008. Lunar Sample Analysis
4009. Returned Solar System Sample Analysis
4010. Microwave Telescope – Extraterrestrial Life
4011. Ionosphere-Magnetosphere Coupling Analysis

are further described in Appendix B. Neither the list of objectives nor the list of potential systems is exhaustive. Chapter 7 describes additional space activities considerably more ambitious than those included in this chapter, many of which seem to be technically feasible before the year 2000.

We consider the technical feasibility of the candidate systems listed in Table 7 to be reasonably good, although not without challenge. A more thorough discussion of future space technology is given in Appendix C and Reference 28.

This chapter does not suggest any programmatic structure for combining themes, objectives, and supporting systems since it was not the purpose of this study to develop program plans. However, examples of program structures are given in Chapter 6 to illustrate how various systems can be combined and time-phased to meet one or more objectives within reasonable budgetary limits.

The following two parts of this chapter, Earth-oriented Activities and Extraterrestrial Activities, describe attractive future space activities, emphasizing the objectives associated with each theme, their rationales, and the system considerations necessary to pursue them.

EARTH-ORIENTED ACTIVITIES

THEME SELECTIONS

The selection of the Earth-oriented themes was based on a consideration of world trends and resulting needs; the basic capabilities afforded by satellites in earth orbit; and past programs and current plans.

Though Earth as seen from space is beautiful (Figure 6), an examination of trends such as those outlined in Chapter 4 reveals the increasingly serious problems of this lovely planet. Those trends which appear to have significant implications for space activity are summarized in Table 8. While space activities directly related to population are not foreseen, population is included because of its driving force in relation to the other trends. It is interesting to note that the areas of food, energy, environment, and communications, all of which represent growing problems, also represent basic requirements of any society.

In selecting our themes and their associated objectives, we reviewed the basic advantages afforded by space flight. A satellite in orbit above the Earth provides a vantage point for repeatedly observing and surveying conditions of the land, oceans, and atmosphere on a global scale. This vantage point, coupled with ground tracking equipment, also permits very precise measurement of the distance between any two points on Earth, which we exploit in a variety of geodetic applications. A satellite in geostationary orbit provides a reliable relay between terrestrial points separated by great distances by the Earth's curvature, which limits direct radio communication.

The immediate environment of the satellite is also potentially significant. It is characterized by near-zero gravity, an ultra-hard vacuum, and radiation conditions

Figure 6. The Earth as seen from space.

unaffected by the Earth's atmosphere. The latter is of immediate importance in the use of solar energy to provide electrical power on Earth.

Many of these advantages have been utilized for years. Advanced continental communications via satellite are significant commercial activities. Domestic communications via satellite have begun, and special service activities such as education and remote medical services have been the subjects of successful experimentation. Meteorological satellites are an integral part of the weather observing and forecasting service. The recent development of meteorological satellites in geostationary orbit provides continuous monitoring of weather and sets the stage for new advances in forecasting. Measurements from scientific satellites have also provided a definition of the upper atmosphere, only sketchily known before.

Much of the manned space program has been Earth-oriented. It has progressed from initial orbital flights of a few hours, through exceedingly complex space operations, to the conduct of extensive manned scientific measurement programs over

Table 8

Summary of Trends of Greatest Influence on Development of Themes 01 Through 06 (from References 2, 5, 10, and 11)

- Population Growth
  - Seven billion people by the year 2000
  - 0.6% annual growth rate in U.S. and Europe
  - 2.5-3.0% annual growth rate in Africa, Latin America, So. Asia
  - Increasing percentage of U.S. population in urban areas

- The World Food Situation
  - Present food production required to double by year 2000
  - North America only major surplus producing region
  - Grain reserves have shrunk from month(s) to week(s)
  - Climate changes may be a significant consideration

- Energy Demands
  - Present U.S. energy requirement of the equivalent of 30 million barrels of oil per day will grow to 80-120 million barrels per day even with reduced growth rate
  - U.S. dependence on foreign energy projected to increase from 5% in 1970 to 30% in 1985
  - Most estimates project that all oil and natural gas will be depleted in the next century

- Environment
  - Projected use of fossil fuels may change surface and air (20 km) temperatures by 1/2°C and 1°C, respectively, between 1970 and 2000
  - Changes in surface and air temperature will have unknown effects on atmospheric circulation and water vapor
  - Man-made chemicals may degrade stratospheric "shield"

- Communications, as a Consequence of Interdependency, Industrialization, and the Pursuit of Happiness
  - Annual growth rate domestic communications
    - 5% local telephone
    - 10% long distance
    - 15% households using CATV
    - 10% fund transferral checks
    - 3% mail volume
  - Overseas telephone calls increasing at 30% annual rate

long periods in space. The Shuttle transportation system now under development and the associated Spacelab, will support many aspects of programs in the 1980s and 1990s.

After consideration of world trends, satellite capabilities, and past experience, we selected the following Earth-oriented themes to provide a structure for defining and evaluating potential Earth-oriented space activities in the coming decades:

Theme 01 – Production and Management of Food and Forestry Resources
Theme 02 – Prediction and Protection of the Environment
Theme 03 – Protection of Life and Property
Theme 04 – Energy and Mineral Exploration
Theme 05 – Transfer of Information

Theme 06 – Use of the Environment of Space for Scientific and Commercial Purposes
Theme 07 – Earth Sciences

In reviewing these Earth-oriented space activities, it should be kept in mind that:

- The particular objectives presented have been selected on the basis of the space capability either to provide measurements or services now being obtained, or representing an improvement over an existing Earth-based system. In both cases, the final decision to implement an objective operationally will depend upon detailed design studies, and in many cases equally detailed economic studies of potential benefits. Since such detailed information was not available for the present study, the objectives we selected were based on our own assessment of available studies and experimental results, coupled with the judgment of people directly involved or contacted during the study.

- Many of these objectives have been previously identified in the context of possibilities or experiments. In the present report we intend to emphasize the need, and the effort required, to bring these experiments into operational utility.

- A significant part of the future effort required to achieve this operational utility is analytical, involving the development of interpretive techniques and predictive models.

- Many objectives can be supported commonly by the same spacecraft and sensors.

- System descriptions and schedules presented herein are illustrative only. Detailed design studies will be required to optimize plans and programs.

Objective 011 – Global Crop Production Forecasting

The purpose of this objective is to provide a bi-weekly forecast of the global production of major crops having worldwide food and/or economic significance. As was noted in Chapter 4, the growing world population requires significantly increased food supplies (Reference 5). With the prospect of a threefold population increase in the next 50 years, primarily in now underdeveloped countries, food production would need to be increased by a factor of six to match U.S. protein standards on a worldwide basis.

Most of the world's nutrition is obtained from small grains such as wheat, rice, and corn. A mixture of plants or a combination of meat and grains can provide a balanced protein diet. However, the caloric conversion efficiency of plants to animals varies from 5-to-1 for cattle (10-to-1 if grain-fed) to 2-to-1 for chickens (i.e., 2 calories of plants to produce 1 calorie of chicken, etc.).

About 97% of the world's food comes from the land and 3% from the sea (Reference 12). While we do not expect that living marine resources will contribute a significant amount to the solution of the world food problem in this century, they are significant in certain areas of the world and are discussed later in more detail.

The elements involved in food production are depicted in the model shown in Figure 7. Space activities might contribute to an increase in food production with improved forecasting of both weather and water availability. Weather modification and mineral discovery are also factors in a food production system, although the potential of space in these areas is less apparent or significant. All four areas are discussed in more detail later in this report.

Figure 7 illustrates the many elements directly related to food production. Planning and management also play significant roles in the ability to meet world food needs. A global crop production forecasting system is an important element of agriculture management. Such a crop production forecasting system exists in the U.S. today but no uniform system of comparable accuracy exists for the world. Figure 8 depicts the elements of a system for global crop production forecasting. Many elements of this system are presently or potentially amenable to measurement from space. Earth-orbiting space systems offer a feasible, systematic approach to global crop production forecasting, with potential improvements over existing national systems.

An accurate global crop production forecasting system offers a variety of potential benefits. These benefits are not uniquely humanitarian, but are closely allied with national economic considerations. World food reserves have shrunk from 26% of annual consumption in 1959 to 7% in 1974. North America is the only major exporting region in the world, and food exports are now a major factor in U.S. world trade and balance of payments. Better global crop production forecasting could provide government "food managers" with information pertinent to trade agreements

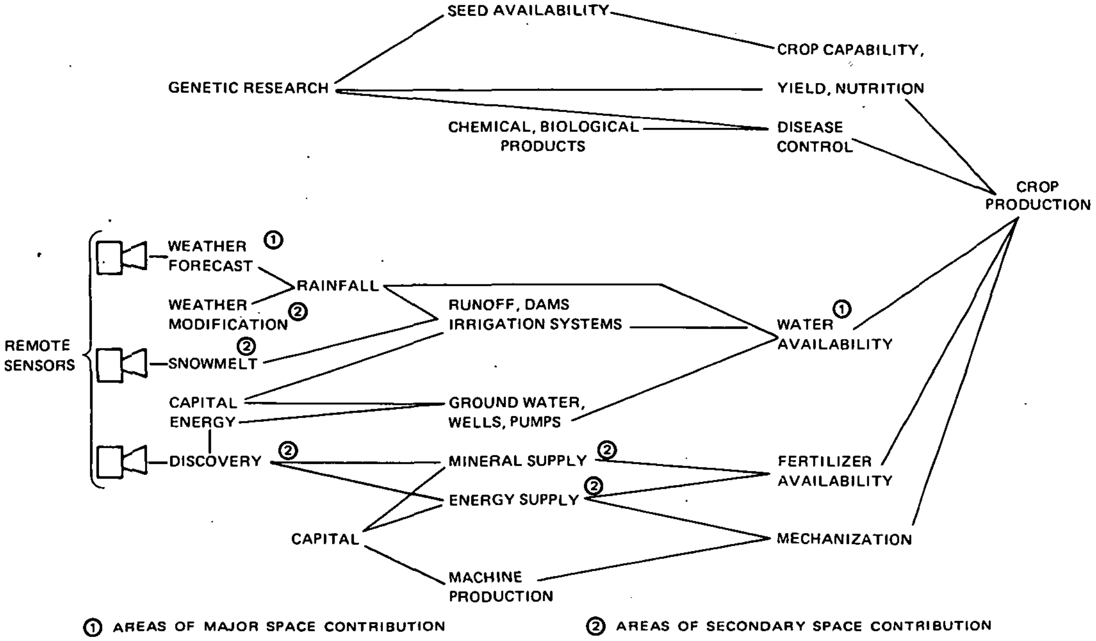

Figure 7. A Model of Food Production

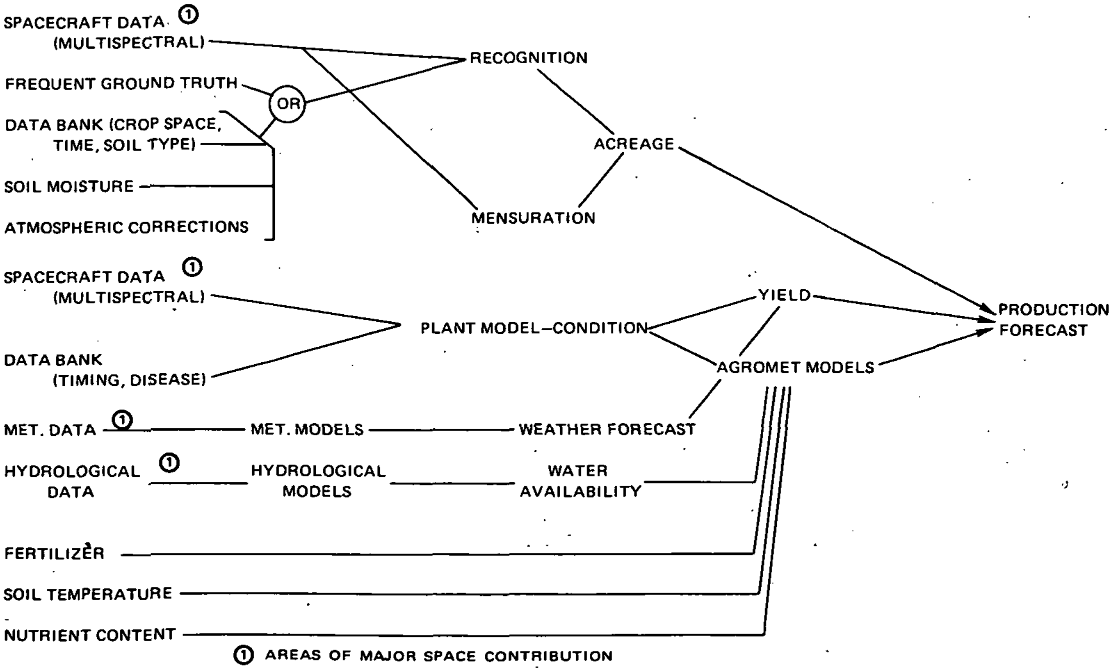

Figure 8. A Model of Crop Production Forecasting

and potential market changes, early warning of crop failures, and data on transportation requirements. Agricultural production could benefit from such information in relation to optimum crop-to-plant, sell-or-use, harvesting, and storage decisions. Resulting economic benefits as high as hundreds of millions of dollars per year, as well as a stabilizing effect on the commodity market, have been estimated (Reference 13).

The Large Area Crop Inventory Experiment, (LACIE), now underway, represents a desirable first step toward this objective. This experiment – based on existing satellite systems for crop inventory, early pattern recognition techniques, and yield models dependent upon historical data – should provide insight into the problems and possibilities of estimating global crop production accurately, and may even result in a degree of operational capability in the next several years.

We project an operational system by 1982 for global wheat forecasting. This system would be based on an improved spacecraft system, optimized pattern recognition and sampling techniques for crop classification, and advanced yield models as compared with those used in LACIE.

In the late 1980s, an improved system could be operational for forecasting the production of all major crops, including improved accuracy in wheat production forecasting. Such a system would require higher resolution measurements to allow for the accurate inventory of the smaller fields which are more common for non-wheat crops. Moreover, the yield of non-wheat crops is more sensitive to environmental factors; as a result, it is a more difficult task to develop yield models.

The 1982 and 1990 space systems are expected to use passive sensors. Consequently, they will require cloud-free conditions to obtain data, or a number of satellites to assure adequate frequency of measurement. By the end of the century, the passive sensors may be augmented by active microwave systems which could penetrate cloud cover and reduce the number of satellites required.

More detailed (but still only illustrative) descriptions of the systems are provided in Table B-4 of Appendix B.

The capabilities which should be developed and demonstrated in the three systems prior to their becoming operational are summarized as follows:

Global Wheat Prediction System

- Plant radiance and agromet yield models
- Optimization of sampling strategies
- More efficient crop classification techniques
- Sensor detectors with adequate signal-to-noise ratios (50:1)

Global All Crop Prediction System

- Sensor signal to noise ratio of 100:1 for high resolution scanner

- Predictive models to incorporate soil temperature and moisture measurements from a "water resources satellite system"

All Weather Global All Crop Prediction System

- Active "cloud penetrating" microwave sensors
- Development of crop classification techniques with active sensors

This objective is presented in specific relation to crop production forecasting. Figure 8 indicates the wide variety of measurements required by the objective. Many of these have potential value in their own right, e.g., crop inventory, crop condition, soil moisture; and they would be used for a variety of specific or local objectives. The space systems required for global crop production forecasting can also provide data for the assessment of arable land, the monitoring of the "health" of the land, the monitoring of rangeland forage status, the control of insects and plant disease, timber inventories, and various aspects of forest management. While all of these objectives can utilize data from the same space network, the ground and analytical elements of the systems will differ, as will be discussed later.

Objective 012 – Water Availability Forecasting

The purpose of Objective 012 is to provide forecasts of water availability for irrigation, hydroelectric power generation and shale cracking based on satellite surveys of snow and moisture. The world's demand for water has increased markedly in the post-World War II era as population has grown and nations have industrialized. Water consumption in America is expected to increase to 1.25 to 4 times the 1970 level (1480 million cubic meters per day – Reference 14). The primary use of water in the U.S. in the 1990 period is expected to be for electric power cooling, irrigation, industrial, and municipal needs, in that order.

On a national level, water availability in the United States appears adequate to the end of the century, but large regional insufficiencies are likely. The West will continue to be the most critical water region of the country. Better water availability forecasting can be a significant agricultural and economic factor in these areas. In addition to municipal requirements, the West needs water for irrigation and to utilize its hydroelectric generation capability most efficiently. These needs may be significantly increased by water requirements due to large scale shale oil processing.

A primary water source in the West is snowfall and melt in mountain regions. This water is managed from a series of reservoirs with flood prevention as a governing criterion. Current forecasts have errors of the order of 25% (Reference 13). Greater accuracy would result in more water for irrigation, power generation, and industrial use rather than being "dumped." The value of this additional water has been estimated at 20 to 50 million dollars per year. Improved measurements for forecasting can come from space system surveys. While directed at a regional need in the U.S., the techniques would be equally useful in other areas of the world which also depend upon mountain snows for water. The extensive mountainous areas, with their associated accessibility problems, plus the need for repetitive observations, make space-located instruments an attractive means of forecasting water availability for irrigation, hydroelectric power generation, and shale cracking.

The target date for an initial operational water availability forecasting capability in selected western U.S. areas could be 1982. This system would utilize subregional prediction models. The space data to feed the models could be provided by the 1982-launched satellite system described for Objective 011, which could survey the areal extent of snow and water cover, augmented by meteorological satellite and *in-situ* sampling.

An improved operational system (projected for circa 1986) would involve spacecraft surveys of soil and snow moisture and water. The satellite system could be equipped with either passive or active microwave sensors operating at several frequencies including long wavelengths (L-band) to allow a degree of subsurface measurements. Regional runoff prediction models based on space measurements of soil and snow moisture will be required. Large antennas (hundreds of meters) will be necessary, particularly if the passive systems are used.

By 1992, the operational system could be expanded to provide regional water balance forecasts. The principal research and development involved in this case is in development of the models. The space system would primarily be developed from the earlier version to provide higher resolution and to reflect product and technique improvements. Table B-4 of Appendix B provides additional descriptions of the illustrative systems.

The capabilities required for development and demonstration prior to the operational systems are:

Water Resource System

- Model development and techniques for estimating moisture content for areal extent measurements.

Watershed Runoff Forecast System

- Regional runoff-prediction model development
- Refinement of techniques for extracting quantitative measurements for soil moisture and water content of snow from microwave measurements.
- Development of techniques for the assembly and deployment of large antennas in space.

Regional Water Balance Forecast System

- Development of ungauged watershed hydrologic models.

Closely related to Objective 012 is Objective 014 which concerns living marine resource assessments. A key parameter in the study of living marine resources is salinity. At present, long wavelength microwave measurements offer the best method of measuring water salinity. Since long wavelength systems are also required for soil and snow moisture, it is apparent that the same space system would support both water availability forecasting and living marine resource assessment. In addition to the common use of the microwave system, Objective 014 would require measurements in the visible and infrared; hence the inclusion of sensors with these capabilities on those systems described in Appendix B for use in water availability forecasting.

Objective 013 – Land Use and Environmental Assessment

The purpose of this Objective is to provide surface cover information and application techniques to support land use planning, environmental assessment and monitoring, and natural resources management. General population growth, accompanied by extensive economic and industrial growth, has placed significant pressures upon finite land resources. Land areas equivalent in size to New Hampshire, Vermont, Massachusetts, and Rhode Island combined will be consumed by urban encroachment by the year 2000. The "urban field" or "impact zone" will include one-third of the area of the U.S. (Reference 15). The siting of nuclear power plants, coastal zone development, mineral extraction from near surface, cropland preservation, recreational needs, and wildlife and wildland preservation and management will cause difficult land resource problems. Space system surveys and associated computer techniques could make available to the public, private, and government sectors land resource information in a systematic, timely, and cost-effective manner. The large area involved, coupled with the need for repetitive, uniform measurements, makes the spacecraft superior to the aircraft platform. The aircraft system will continue to be superior for small areas where intensive, one-time study is required for a particular application.

Numerous federal and state laws directly or indirectly pose a need for land resource information. Existing estimates of economic benefits range from $10 to $115 million per year based on varying assumptions, not accounting for any improvement in the "quality of life" (Reference 13).

The foregoing comments have been directed primarily to the situation in the U.S. and other developed nations. Developing nations need this type of activity to support the planning of land for initial use. The food requirements stemming from population pressures result in a particular need for the assessment of arable lands, which requires data on soil characteristics, water availability, climate and geological parameters, in addition to the surface cover information. Space survey data, with associated information extraction techniques, could provide an attractive vehicle for foreign aid and international cooperation.

In addition to supporting effective land use, space activities can provide surface cover information for environmental assessment and monitoring and for natural resources management. The wide variety of applications supported by this objective implies a wide variety of users, involving all levels of government and industry in all sections of the world. Consequently, the pursuit of this objective must involve the generation and transfer of data, information and techniques internationally. The plan to implement a "transfer" activity presented in the following paragraphs is illustrative only.

A technical center might be established in each federal region (by 1982, for example) to provide spacecraft data, information, techniques, and consultation to users. Data would result primarily from the satellite system required for Objective 011. Initially, technical centers would have a capability for data reception from ground receiving stations; information extraction; and selected product (tapes, etc.) preparation. Personnel would be trained in information extraction and application of satellite data to a variety of problems, and would provide consultation and support in integrating satellite information into existing information systems which utilize data from a variety of sources.

The technical center capability could be upgraded by 1990 to receive data directly from satellites and do the necessary preprocessing. Improved software, hardware, and personnel training would be required to utilize the greater resolution and variety of data resulting from the improvement of the space systems of the crop forecasting activity.

Prior to the systems' becoming operational, the following should be demonstrated in the development phase:

Surface Cover Change Detection System

- Cost effective pattern recognition program
- Coordinate reference software
- Inexpensive interaction data analysis hardware and software

Critical Environmental Area Monitoring System

- Further refinement of software for high resolution data
- Low-cost antennas for direct receipt of large volume of data

Land Capability System

- Information models utilizing both space and surface measurements.

Objective 014 – Living Marine Resource Assessment

The purpose of Objective 014 is to develop a living marine resource assessment and management system for one or more presently utilized coastal species in the U.S. Living marine resources will not contribute substantially to meeting the total food needs of the world, since fisheries currently provide only 3% of the world's food supply (Reference 12). Such resources are important, nevertheless, to the food and nutrition requirements of many regions of the world. Estimates of world yield range from near the present yield (70 million metric tons annually) to as much as 30 times the present yield.

With the technology available today, it is impossible to confirm what the real potential increase may be in productivity from the ocean. Therefore, it is difficult to determine how important living marine resources may be to the increasing world food needs. The contribution of mariculture to this increase is expected to be insignificant before the year 2000. Generally, the increase in productivity would come from more efficient use of presently used species, with some use of new species. A small sample of opinions from government and industry personnel indicated that our present priorities should be the better use and management of presently used species, followed by an increased emphasis on use of new species, in turn by an increased emphasis on the development of mariculture techniques.

If the conservative estimates are correct, living marine resources as a source of food will not solve the world's food problems at any time in the future. However, if the optimistic estimates can be approached through better knowledge, management, and mariculture techniques, living marine resources can provide a significant part of the global protein needs after the year 2000. Therefore, marine resources as a food source in the long term should be thoroughly evaluated.

We suggest the development of the capability to predict continuously the location and quantity of at least one species of fish in an area, to support proper management of the fishing resources. This fishery assessment could be determined from environmental measurements using satellites and buoys. The assessment information would be used to optimize harvest in proper balance with conservation. The large areas involved, coupled with the need for frequent measurements of a dynamic regime, require satellite systems since the cost of buoy systems alone would be prohibitive.

Comprehensive studies of the cost benefits of a fishery assessment system are not available for coastal species. For oceanic species, however, one study indicates that a 50% reduction in search time for tuna, combined with a 25% increase in catch due to better information, would yield an annual operating cost reduction of 12 million dollars plus an annual fleet investment cost reduction of 6.4 million dollars.

The need for such an assessment system, however, is based on the fragility of the seas as well as their economic contribution to food and protein sources. Examples of fish crop damages or depletion are many: e.g., the disappearance of the Peruvian anchovies, and of the California sardine after World War II; and the destruction of the New England shellfish crop. While it is thought that these failures stem largely from overfishing, the phenomenon is not well understood.

The importance of such a management system is to prevent such localized phenomena and the associated economic perturbations. A modest increase in overall world animal protein supply production might also be expected from this objective, and significant increases in food might be possible in the post-2000 period using mariculture techniques. This objective would help to ensure the perpetuation of living marine resources and provide information on which to base a future mariculture industry. A negative effect of this activity would result if the information were used for over-harvesting instead of management purposes.

An operational system might provide, by the year 2000, weekly forecasts of the location and quantity of a coastal species such as menhaden in one coastal area (Gulf of Mexico, or off the Atlantic coast). The satellite network of Objective 012, the Water Availability Forecasting objective, could be utilized. This system includes the scanning spectrometers for water color and surface temperature measurements, in addition to the salinity and temperature measurements derived from the microwave system. The total system would also include environmental, biological, and harvesting models. The activity would be conducted in a coastal forecasting and management center which would also inform the fishing fleet of weather, marine conditions and position location, as well as harvest management information – thereby requiring outputs from a number of satellite systems and forecasting centers. The network of buoys providing chemical, biological and subsurface data would number about 150 for a coastal area.

Environmental measurements from satellite systems described for the crop and water forecasting objectives may be also used for the study and monitoring of marine mammals. The interpretation of such measurements might require preliminary studies involving instrumented animals, with satellite relay of data, to establish environmental biological relationships.

Before operational systems are implemented, the following capabilities need to be demonstrated in the developmental phases:

- Techniques for extracting accurate measurements of chlorophyll and turbidity from water color measurements in coastal waters.
- Large antenna (100-300 meters) microwave antenna assembly and deployment in space for salinity measurements.
- Establishment of the relation between environmental parameters and the habits and characteristics of the species.
- Develop prediction models for parameters (environmental, biological) separately and integration into forecasting model.

Objective 015 – Timber Inventories

The purpose of this objective is to develop and implement a capability to inventory the timber of the nation's forests on a five-year cycle with yearly update based on multistage sampling techniques using satellites and aircraft. Within the continental United States, about 33% of the total land is forested, and about 13% is classified as rangeland, (with 27% of the forestland, and 31% of the rangeland in public ownership). On a worldwide basis, about 29% of the land area is forested, and 27% is classified as rangeland (Reference 16).

Forestland or rangeland may be used for one or more of the following purposes: fibre production, watershed, recreation, grazing wildlife, preservation, and food production. In the United States, public forestlands are generally managed for a variety of these uses, but multiple use as a management concept gradually breaks down as management plans deal with smaller and smaller areas. Management of private forestland held by large companies is generally oriented to fibre production, with other uses being secondary or incidental. Small private holdings, if managed, tend to emphasize fibre production, but frequently are found in an unmanaged state. Rangeland is generally managed or used for grazing, wildlife habitat, and/or as watershed.

On a worldwide basis, the largest extent of forest is found in tropical wet areas in developing countries (e.g., Brazil) and in cold areas (e.g., Siberia); whereas, rangeland is most extensive in areas falling between the tropical wet and cold extremes. (Tundra is not normally classified as rangeland and therefore is excluded, although it is often used for grazing and wildlife.) Except for livestock grazing, food production is not an important use of forestland in the United States; however, food production through slash-and-burn and other indigenous systems is considered a legitimate and important use of tropical and subtropical forestland.

During the last 25 years, the U.S. produced about 90% of the timber products it consumed; production increased about 15% and now stands at about 0.4 billion cubic meters (13 billion cubic feet) annually, but per capita consumption of timber products declined about 20%. U.S. consumption of certain timber products, such as paper products, however, increased over 70%, and worldwide consumption of newsprint is following similar trends. Because of costs, the U.S. imports almost 70% of the newsprint it consumes.

In order to help ensure conservation and proper utilization of the nation's forests, a national forest inventory was authorized by the McSweeney-McNary Act of 1928. These data are used for policy, planning, and administrative decisions. The inventory is conducted on an 8 to 15 year cycle in different areas of the country, with a midterm update in some areas. The national forest inventory is conducted by the Forest Service. Specific ownership surveys are also required, and these are conducted by a number of agencies, companies, and states. The data are used for the management of forestland with respect to logging, thinning, planting, and other silvicultural activities. They require more detailed measurements than those for the national forest inventory.

The large portion of the U.S. covered by forests leads to the potential application of space systems to support the national forest inventory and, ultimately, specific ownership surveys. Estimates of economic benefits from a combined spacecraft/aircraft system range from 1 to 3 million dollars for the national forest inventory to 27 million dollars when forestry information is used in forest management decisions (Reference 13).

Direct international cooperative activities are not apparent, but the concept is applicable to world forest inventory activities carried out by the Food and Agriculture Organization of the United Nations. The techniques and technologies are suitable for use in both developed and underdeveloped countries, and can be "exported" in support of national policy.

In view of the large extent of forested areas and the ability to survey such large areas rapidly from space, we believe it is important to pursue the capability to inventory the timber of the nation's forests on about a 5-year cycle, with yearly updates based on multistage sampling from space and aircraft, and subsequently to achieve the capability for specific ownership surveys.

Should this objective be pursued, each federal forestry region could (by 1982, for example) be able to use the spacecraft data generated by the crop forecasting system to conduct the national forest inventory. This capability would require, in addition, aircraft and field measurements to support the multistage sampling techniques, as well as software and associated computers.

By 1990, an operational capability may be envisioned to use data generated by the flight systems of the crop forecasting objective to conduct timber inventories of specific ownerships, and to reduce the aircraft support requirements of the national forest inventory. Software and analysis techniques must be upgraded to utilize higher-resolution data from the crop forecasting system.

Prior to operational capability, the following should be accomplished in the developmental phases:

Broad Area Timber Inventory System

- Optimization and demonstration of multistage sampling techniques
- Technique for handling of mixed species

Specific Area Timber Inventory System

- Extension of techniques to high-resolution data to achieve required accuracies

Objective 016 – Rangeland Assessment

The purpose of this Objective is to provide timely assessment of range conditions to support efficient cattle management. Foods from grains and marine resources have been addressed. A third important source of food is animals. Our consideration of this source is in the context of rangeland. Since its predominant use is for food production through the grazing of livestock, rangeland is intimately linked with cultivated land.

The consumption of beef per capita is growing more than 3% annually, and the increased cost of grain feeding results in increased use of range feeding. Grain fed, commercially slaughtered cattle constituted 80% of the total in 1973 but are expected to be only 50% in 1975. Continued rises in demand and grain prices result in a need for better range-fed cattle management. It is possible to contribute to this improved management by using spacecraft surveys of the rangeland as a basis for a weekly status report of range conditions. The use of spacecraft data becomes effective in the large areas of the West where grazing conditions are often marginal and the cattle need to be optimally located. Estimated economic benefits derived from this Objective range from 4 to 30 million dollars annually (Reference 13).

A range condition status center could be implemented by 1982 in the western U.S. (e.g., Denver) to provide weekly reports on vegetation in grazing areas. Status reports would be based on spececraft data from the crop production system, utilized with vegetation "models." The development of these models is a pacing activity. By 1990, models could be developed to allow prediction as well as status, using variations of agromet yield models developed for Crop Forecasting under Objective 011.

Necessary accomplishments during the developmental phase of the systems are:

Range Forage Station System

- Development of empirical vegetation models

Range Forage Prediction System

- Development of agromet 'yield' models for range vegetation
- Optimization of vegetation models to use with high resolution data

All Weather Range Forage System

- New signature techniques and models for use with active microwave systems.

Summary Observations on Theme 01

Six potential space objectives have been described in relation to Theme 01, Production and Management of Food and Forestry Resources. Additional potential objectives recognized as significant to this theme are weather forecasting and modification, climate prediction, and education in rural areas via communication satellites. These objectives are described under subsequent themes – such as "Protection and Prediction of the Environment" – where they have equal or greater applicability. The following summary observations pertinent to Theme 01 also include comments related to those objectives which are discussed later in this report:

- Accurate global estimates of crop production will provide information for improved food management decisions which will have both world humanitarian and national economic consequences.
- The Large Area Crop Inventory Experiment (LACIE) represents a desirable first step in the development of an operational Global Crop Production Forecasting System based on satellite surveys.
- A higher resolution (~ 30 meters) and higher frequency of coverage (three to nine days) system will improve wheat production forecasting accuracies through access of smaller fields and will allow forecasting of additional crop types of significance.

- A detailed study of the accuracy improvements associated with a very high resolution system should be undertaken to ascertain its desirability.
- The use of higher resolution systems and the resulting data loads will result in a need for better automated classifications and computing techniques. Such techniques are under development and should be recognized as an integral requirement for improved system operation.
- Cloud cover represents an operational constraint of some severity, and research to develop crop identification techniques employing "cloud penetration" sensors should be undertaken for use in the long term.
- Crop production forecasting is equally dependent upon crop acreage inventory and agromet yield models. The development of the latter in a form able to utilize satellite measurements should receive significant attention.
- Yield forecasting models depend upon measurements of soil moisture and soil temperature. Space techniques and systems to measure these parameters require development effort.
- Improved water availability forecasting can be a significant agricultural and economic factor in areas where irrigation is prevalent and water is primarily obtained from mountain snow melt.
- Water availability forecasting models based on satellite measurements of snow moisture content promises improved accuracies as compared with present techniques.
- Continued technique development with aircraft testing, as well as development of techniques for the assembly and operation of microwave systems in space, are needed for snow and soil moisture and salinity measurements.
- Weather forecasting and modification, both large-scale long-range and local-near-time, are significant to agricultural activities. Agricultural/weather relationships should be analyzed in depth to insure optimum support to this critical activity (see Theme 02) in the implementation of weather programs.
- Long-term climatic changes may have profound effects on food production in a given area. The monitoring or prediction of long-term trends could provide a tool to ward off impending catastrophe and/or long-term economic deterioration (see Theme 02).
- Seasonal regional climate predictions could support numerous agricultural related decisions including transportation-distribution, crop type and strain to plant, etc. (see Theme 02).
- Space systems required for global crop production forecasting can provide data to support the assessment of arable land; monitor the "health" of the land, rangeland forage status; control of insects and disease; timber inventory; and various aspects of forest management. These activities all contribute to

food and forest production and/or management. To effect these applications, however, specialized analytical techniques are needed, and appropriate effort should be focused on this aspect of the problem.

- Living marine resources do not provide a large percentage of the world's total food need at the present time, but do have present regional significance, and an unknown potential for increased yield and possible extensive mariculture activities in the next century.
- The technical difficulties of a living marine resource assessment and management system are considerable. However, a long-term research effort is desirable to develop the environmental-biological relationships on which a future system would be based. Satellites, with their ability to survey large areas in short times, provide a unique capability for the study of these relationships.
- Experiments are now underway to bring educational information to rural areas via communication satellites. Such activities may be uniquely beneficial in improving farm practices and should be carefully studied for potential exploitation in many areas of the world (see Theme 05).

THEME 02: Prediction and Protection of the Environment

The quality of the Earth's natural environment has been the subject of increasing concern especially in the last decade. This is true not only in industrialized countries, but also in developing countries whose industrial and technological growth has just begun. In the U.S. there is the need to monitor and protect the environment from human neglect. Throughout the world, it is the environment that determines, in the end, whether humanity can survive. Weather, climate, and natural disasters are among the oldest concerns of humanity.

In this theme, we address weather in all its aspects (except for local weather and severe storms, which are covered in the next theme) and the need for experiments in weather modification. We also discuss the much larger subjects of climate prediction, with all its implications for human well-being, and water quality, which is presently a serious problem in the U.S. We discuss the stratosphere, both because there is concern over possible changes due to human activities and because of its poorly understood role in the total environment.

Activities discussed in other themes which also contribute to this theme are: Water Availability Forecasting; Land Use and Environmental Assessment; Local Weather and Severe Storm Forecasting; Tropospheric Pollutants Monitoring; Hazard Forecasting from *In-Situ* Measurements; Communication-Navigation Capability; Solar-Power Stations in Space; Power Relay via Satellites; Hazardous Waste Disposal in Space; Domestic Communications; Intercontinental Communications; Dynamics and Energetics of Lower Atmosphere; Structure, Chemistry, and Dynamics of the Stratosphere Mesosphere; and Ionosphere-Magnetosphere Coupling.

Objective 021 – Large Scale Weather Forecasting

The purpose of this Objective is to improve operational systems for large scale weather forecasting. With the growth of technology, weather exerts a greater influence on human activities and on the potential to exploit the Earth's natural resources. Improved capabilities in predicting weather would permit more efficient development and use of the available resources.

Many facets of the American economy and societal activities depend to some degree on the weather and our ability to make accurate and timely forecasts of changes in the weather. Total economic losses due to weather are estimated to be of the order of 12 billion dollars per year, of which 5 billion dollars are estimated to be preventable (Reference 17). Better weather forecasts for periods of up to 30 days could reduce these losses by an estimated 500 million dollars per year. Primary losses and potential benefits are focused in the area of agriculture.

In order to improve the accuracy and extend the useful range of large scale weather forecasting, the international scientific community has organized the Global Atmospheric Research Program (GARP) and is now planning the details of the major activity of that program, the First GARP Global Experiment (FGGE). The basic elements of the global experiment are an observing system and a data processing system. The observational phase of the experiment, to commence in late 1978, involves the measurement of the large-scale state and motion of the entire atmosphere over a period of approximately one year. The data processing aspects of the experiment involve the conversion of instrument readings to useful meteorological variables and the use of these data in numerical models of the general atmospheric circulation for long-range, large-scale weather forecasting. The goal is to improve forecasting accuracy and an extended useful range of forecasting from the present three days toward the ultimate limit of predictability, estimated to be between 10 and 20 days.

The success of FGGE is predicated upon obtaining global observations of the state of the atmosphere at least once every 12 hours. The primary platforms for these observations are two to four Sun-synchronous polar-orbiting satellites with instruments for measuring atmospheric temperature and humidity and sea surface temperatures, and five geosynchronous satellites returning visible and infrared images for deriving winds, cloud amounts, and cloud heights. Winds and boundary layer parameters are also obtained by satellite tracking and collection of data from free-floating balloons, ocean buoys, and remote monitoring stations.

Global observations are essential to these goals; and spacecraft provide the only practical method for such observations. In addition to its direct benefits, improved forecasting of large general atmospheric circulation also provides the basis for local weather forecasts, including forecasts of mesoscale phenomena such as severe storms. The forecasting of these localized, near-time phenomena will be a focus of the 1980s. The understanding of the large general atmosphere circulation will also play a role in weather modification and climate programs. Research and operational meteorological programs contribute to both requirements and the necessity of international cooperation because of the dynamic, global nature of the atmosphere.

In order to pursue this objective, a continuing research and development program leading to improved operational systems would be required.

By 1985 an operational system based upon the results of the GARP global experiment could be implemented. The network would include two to four satellites in near-Earth Sun-synchronous orbit. It would also include satellites in geostationary orbit which serve the dual purpose of supporting large-scale weather forecasting, and severe storm and local forecasting as described in Objective 031. Measurements of sea and air temperature and humidity would be obtained every 12 hours for a horizontal scale of 100 km. Winds would be measured on a horizontal scale of 200 km by tracking clouds with images from geosynchronous satellites and by tracking free-floating balloons. Polar and sea ice would be measured every five days at a scale of 30 km. In the mid-1980s an experimental system to measure with doppler radar could be deployed.

In the early 1990s, an improved system, consisting of four satellites in near-Earth Sun-synchronous polar orbit and three three-axis stabilized geosynchronous platforms, could be operational. Measurements would be made on a horizontal scale of 50 kilometers (10 kilometers for ice). Active near-infrared sensors would be used for temperature and humidity profiles and wind measurements would be obtained with a multifrequency doppler system.

Developmental accomplishments prior to operational capability are summarized as follows:

- Refinement of numerical models to include boundary layer energy transfer, moisture convection, and parameterization of sub-grid phenomena
- Air-sea interaction
- Radiation transfer and dynamic processes
- Soil moisture and precipitation measurement techniques
- Expanded computer capacities
- R&D activity on active near-infrared sensors for temperature and humidity profiles

Objective 022 – Weather Modification Experiments Support

Satellites can be used in the future to monitor weather modification activities. Possible desirable areas of weather modification include: increase or decrease of rainfall, reduction of the intensity of severe storms, delay and/or minimizing the onset of frost, and smog abatement. An effective weather modification system would have numerous benefits. The alleviation of drought and the optimization or improvement of agriculture growth conditions would have large economic and humanitarian benefits. Alleviation of severe storms would save lives and injuries, and decrease damage. Any program of weather modification, however, must be preceded and accompanied by an extensive analytical program. Both positive and negative, direct and indirect effects must be well understood before a secure program can be undertaken. International cooperation may be desirable, if not necessary, for large-scale efforts.

The most likely direct means of modifying weather is by use of ground-based (including aircraft) delivery systems. Space tools such as solar energy collectors and focusing mirrors should be studied, however, for possible future application, but it is unlikely that they could be useful before the year 2000. The most probable use for space activities in the foreseeable future, however, is the support of weather modification experiments with satellite monitoring systems, measuring conditions prior to, during, and after the experimental activity.

Satellite systems associated with the Large-Scale Weather Forecasting Objective (Objective 021) could also provide support to weather modification experiments. Since the activity would often require high-frequency and high-resolution coverage, the system associated with Local Weather and Severe Storm Forecasting (Objective 031) would be a major area of support. Key research and development for the monitoring support involve higher-resolution sensors for use in geosynchronous orbit, and the associated numerical computation techniques for information extraction. While the monitoring activity itself is relatively straightforward, the ability to forecast what would have happened in the absence of the experiment is a function of our basic forecasting capability as described in the objectives. The weather modification activity itself would involve an increased understanding of microphysical processes and mesoscale phenomena. By 1985, a high-resolution monitoring system could be in geosynchronous orbit to support modification experiments.

Prior to operational systems capability the following would need to be demonstrated:

- Development of higher resolution sensors for use at geosynchronous orbit
- Development of numerical computation techniques for information extraction
- Increased understanding of microphysical processes and mesoscale phenomena

Objective 023 – Climate Prediction

The purpose of this objective is to determine the predictability of climate on various time scales and develop seasonal and longer period forecasting capability. Recently the study of climate and its implications have received new impetus because of the potential effects of various human activities, e.g., the supersonic transport, fluorocarbons in aerosol sprays. We have achieved a level of industrial activity that is affecting the weather, at least locally, and may have long-range effects which modify the climate. Effects on weather, such as those caused by urban development, deforestation, and concentration of energy-generating and manufacturing activities, have been documented, but the direction, extent, and consequences of the resulting climate changes are unknown. The possibility that such changes could appreciably alter our environment in the not-too-distant future, and pose a danger to our way of life, must be given serious consideration. To assess the situation and develop appropriate responses, we must have a thorough understanding of the physical and chemical processes in the atmosphere and oceans and how these processes are affected by humanity's alteration of the Earth's surface and by the effluents from industrial activity.

Before we can assess the anthropogenic effects, the natural processes which affect climate must first be understood. The Sun is the ultimate force which drives atmospheric circulation; but are there variations in the Sun's energy output which are affecting weather and climate?

On several occasions in recent history major volcanic eruptions (e.g., the biggest one was Krakotoa in 1883 and a recent one was Agung in 1963) have injected dust high into the stratosphere, with optical effects lasting many years. The roles of these and similar events in modifying weather and climate must be determined.

Also, we must consider the oceans, which are almost as important as the atmsophere in transporting the excess energy supplied by the Sun at low latitudes to the higher latitudes. What changes are taking place in the oceanic circulation, what causes these changes, and how they affect weather and climate must also be investigated.

Improved forecasting of expected seasonal conditions and climatic trends would make significant contributions to the management of food and energy, and associated transportation requirements. Economic benefits of improved seasonal forecasting are estimated to be of the order of several hundred millions of dollars annually (Reference 17). The economic costs of small climate changes, possibly or partially resulting from human activities, have been estimated to be of the order of billions of dollars a year (Table 9). There is no doubt that such climate changes are occurring, as Figure 9 shows. We are unable, however, to define the conditions causing these changes.

Table 9

Estimates of Economic Costs of Climatic Change (from Reference 21)

Impact Studied	Annualized Cost (Millions of 1971 Dollars)					
	-1° Change in Mean Annual Temperature			+0.5% Change in Mean Annual Temperature		
	Change in Precipitation			Change in Precipitation		
	None	+12%	-12.5%	None	+12.5%	-12.5%
Corn Production	-20.8	-20.1	-21.6	14.4	14.1	14.8
Cotton Production	11.0	10.4	8.6	-2.9	-3.7	-2.9
Wheat Production	92.0	?	?	?	?	?
Rice Production	956.0	1,083.0	918.0	0.0	0.0	0.0
Forest Products	1,790.0	?	?	?	?	?
Douglas Fir Production	474.6	364.9	582.8	?	?	?
Marine Resources	1,431.0	1,785.7	2,434.3	?	?	?
Water Resources	-1.6	9.6	105.0	5.0	53.8	6.2
Health Impacts (Excl. Skin Cancer)	2,386.0	6,484.6	1,896.2	?	?	?
Urban Resources						
Wages	3,667.2	5,445.3	1,861.4	-1,550.9	-1,550.3	-1,552.0
Residential, Commercial and Industrial Fossil-Fuel Demand	175.8	175.8	175.8	-87.9	-87.9	-87.9
Residential Electricity Demand	-41.0	-41.0	-41.0	19.391	19.391	19.391
Commercial Elec. Demand	-707.0	-707.0	-707.0	333.5	333.5	333.5
Housing & Clothing Expend.	506.5	506.5	506.5	-253.3	-253.3	-253.3
Public Expenditures	23.8	36.4	15.1	-10.7	-16.9	-5.9
Corn-Belt Investment Costs	51.0-67.0	51.0-67.0	51.0-67.0	?	?	?

A data base on climate is needed on a region-by-region basis to determine climatic trends and periodic behavior. The data should be sufficiently complete that real climate changes can be distinguished from normal weather fluctuations. Observations needed for the data base are summarized in Table 10 (Reference 18) and would

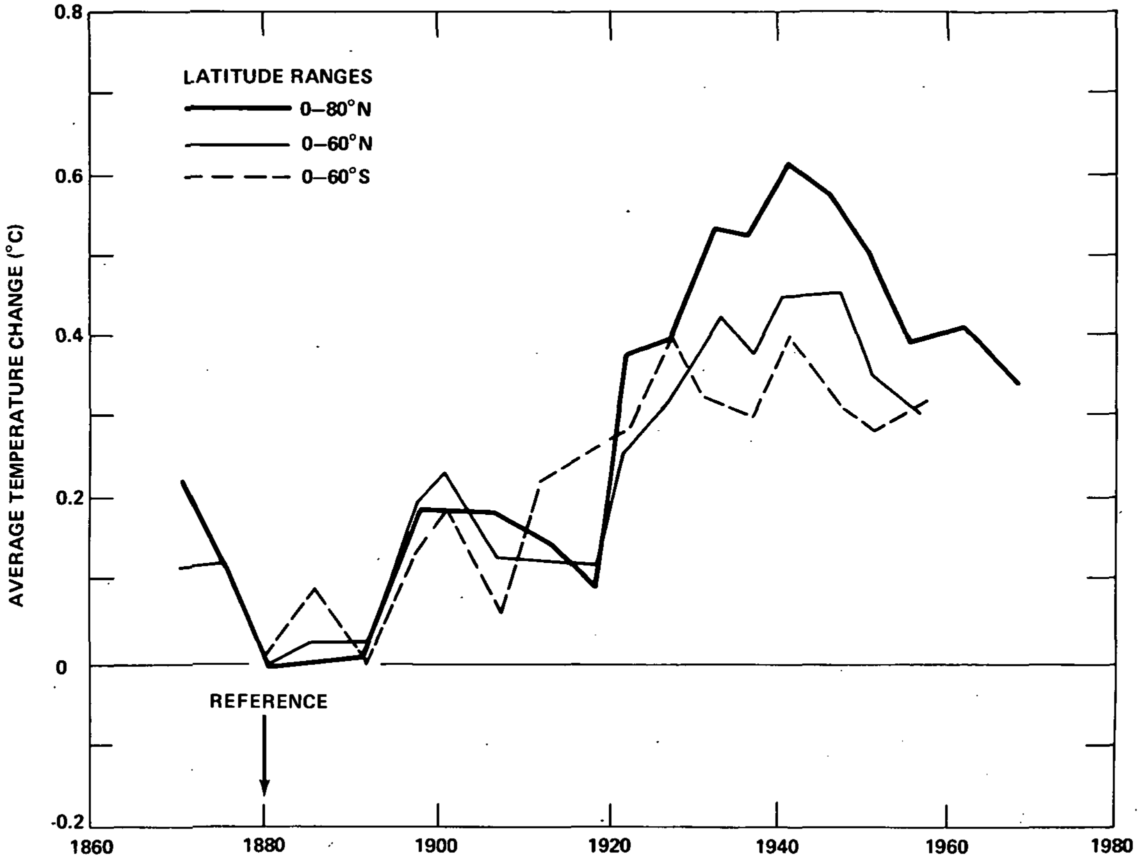

Figure 9. Climatic Trends (Reference 20)

require the combined capabilities of anticipated weather, land, sea, and stratosphere monitoring spacecraft as well as additional systems uniquely tailored to climate requirements. A similar set of observational requirements is presented in Table 17 of Reference 19. Subsurface ocean measurements would require buoys with data relay satellites. Ground and rocket observations would be required at discrete points for spacecraft calibration or to obtain data unavailable from spacecraft. A significant analytical and modeling effort would be required, including deep-ocean circulation, atmospheric particulates, and the Earth's radiation budget.

The global and repetitive nature of the observations implies the need for satellite systems. This need for measurements from space, coupled with the importance of climate to so many aspects of our society, results in its selection as a potential space activity. of the next few decades. A reasonable goal to achieve before the year 2000 might include the determination of the predictability of climate on various time scales and the development of seasonal-to-one-year forecasting capability for regional areas and up to ten-year forecasts on a hemisphere scale.

Table 10

Climate Observations Required (Reference 13)

RADIATION BUDGET
• Total Solar Flux
• Solar UV Flux
• Net Budget
• Cloudiness
	SURFACE RADIATION
	• Temperature
	  • Sea
	  • Land
	  • Ice
	• Surface Albedo
		HYDROLOGICAL
		• Ocean Precipitation
		• Soil Moisture
		• Lake Water
		• Water Run-off

SNOW/SEA ICE
• Areal Extent
• Sea Ice
  • Thickness
  • Melting
  • Drift
	POLAR ICE SHEETS
	• Thickness
	• Deformation
	• Boundary Change
		ATMOSPHERIC GASES/PARTICLES
		• Carbon Dioxide
		• Ozone
		  • Distribution
		  • Total
		  • Profile
		• Aerosols
		  • Tropospheric
		  • Stratospheric

	OCEAN MODEL VALIDATION • Surface Temperature • Upper Layer Heat Content • Wind Stress • Surface Currents and Eddies • Near Surface Currents • Deep Ocean Circulation	

It may be expected that by 1985 a greatly improved data base would exist, including an organized climate monitoring program, a better description of present trends, and identification of most of the important factors influencing climate.

A number of space systems are required to meet this objective. They include those listed for Water Availability Forecasting (Objective 012), Large-Scale Weather (Objective 021), Stratospheric Changes (Objective 024), Global Marine Weather (Objective 026), and Severe Storms (Objective 031), as well as the systems described below. In addition, satellite systems are required for radiation budget data.

A parameter of possible significance to the exploration of the climate question is the solar constant. A solar monitoring system is described later in this chapter. If the research and development program is successful in permitting the active prediction of climatic trends, we expect that an operational phase would follow.

Accomplishments in the developmental phase prior to operations are:

- Better definition of parameters controlling climate
- Establishment of global data base
- Air/sea, Sun-Earth, intra-atmosphere and ocean energy transfer processes

- Understanding of various feedback mechanisms (between ocean and atmosphere and land surface and atmosphere) which control climate
- Development of climate predictive models.

Objective 024 – Stratospheric Changes and Effects

The purpose of Objective 024 is to identify and monitor man-made and natural changes in the stratosphere and assess their impact. There is growing recognition that a delicate balance exists between the composition of the atmosphere and world climate, and solar radiation reaching the Earth, and that this balance may be upset by the actions of human society. Economic growth, spreading industrialization, and the concomitant discharges of industrial and consumer wastes have created a worldwide need for environmental protection.

One potential problem is a predicted depletion of stratospheric ozone due either to operation of high-altitude aircraft and/or the release of fluorocarbon aerosols into the atmosphere. A Harvard University team predicts (Reference 22) ozone depletion of between 3 and 30% by the year 2000 depending on the rate of industry growth, aircraft operation, and government regulation. The effects of particulate loading of the atmosphere by industry are another source of concern. These changes could result in either an increase or a decrease in solar ultraviolet flux at the surface and modify the planetary thermal balance with resulting changes in average temperature distribution, extent of snow cover, and size of polar ice caps. In the atmospheric system, there are many counter-balancing feedback loops and it is not possible to positively state what changes will result from these activities.

The impact of industrial pollution in the stratosphere is extremely difficult to assess and remedial action will be expensive and controversial. It has been proposed that production of chlorofluoromethanes should cease because of alleged harm to the stratospheric ozone layer. These compounds and their related products represent an 8 billion dollar business which employs several hundred thousand people. Therefore, any corrective action must be on a well founded understanding of cause and effect.

Despite this, the attempt to correlate our activities with biological and climatic effects must continue; the climatic effects are of particular concern since they can affect the global food supply. The major problems in the correlation work will not be that of making the measurements but, rather, that of determining which changes are caused by human activity and which are due to natural variability. Thus, the desired correlations will require many years of continuous observation and associated analyses.

The many types of observations associated with the understanding of climate and its variations are described under the discussion of Climate Forecasting (Objective 023). The present objective is directed toward a subset of these measurements associated with the stratosphere and more particularly, those acts of human beings which affect the stratosphere. The primary parameters of concern, therefore, are ozone, aerosols, and CO_2, and those pollutants which interact with these parameters, such as water vapor and the oxides of nitrogen. Past meteorological spacecraft have provided measurements of the global distribution of ozone and planned satellites will be dedicated to the measurement of vertical profiles of tropospheric and stratospheric constituents. Satellites are also being proposed to obtain measurements of aerosols in mid- and equatorial-latitudes to complement the high-latitude measurements. Future activities will include higher accuracies, improved measuring techniques, and increased number of pollutants being monitored. These will include high-resolution laser radars for vertical profiles of aerosol distribution, vertical distribution of trace constituents and aerosols, and laser absorption techniques for the measurement of O_3, NH_3, C_4H_2, and SO_2. The need for supplementary measurements (Dobson networks, ground-based lidar, balloon and rocket soundings) must not be overlooked. Present one- and two-dimensional models of the chemistry and dynamics of the stratosphere will have to be extended to three dimensions, including an understanding of the roles of Cl, H_2O, O_3 and HNO_3 in radiation and heat transfer. The relation of this objective to Objective 023 has already been described. It is also closely related to Objective 032, Tropospheric Pollutants.

A successful research program could lead to an operational monitoring system. By 1985, such a system might consist of two to four satellites in near-polar low-Earth orbits. Instrument complements would reflect the results of currently planned missions. An advanced system in 1993 could have improved instrumentation, such as high-resolution laser radar for vertical profiles of aerosols distribution.

Objective 025 – Water Quality Monitoring

The purpose of this objective is to provide a capability for the use of satellite techniques for water quality evaluation and management. The Federal Water Quality Act of 1972 is aimed at halting the discharge of pollutants and seeks a dramatic upgrading of the quality of continental waters by 1985. Enforcement is based on specifying limits of effluent characteristics such as coliform bacteria, chemical content, oxygen, oxygen demand, pH, temperature, etc. The estimated expenditures in 1971 for efforts to reduce water pollution was approximately 6 billion dollars (Reference 23). Further, the Marine Protection, Research and Sanctuaries Act of 1972 regulates ocean dumping, thus affording specific protection for our offshore marine environment.

The perspective from space provides the broader view of the effects on water quality that is required for certain aspects of effective management. Water quality degradation seldom remains a local problem, but rather becomes regional in scope in a very short time. Spacecraft techniques are being developed which can assist in evaluating and managing water quality. A few of the most important water parameters may be remotely monitored from space (surface temperature, salinity, chlorophyll content, sediment distribution) with varying degrees of accuracy and resolution. Current research work is directed toward, and should lead to, quantitative measurement of other parameters of interest and refinement of present techniques. The relay of data from data collection platforms through satellites is an already proven space technique potentially useful to this area. This approach can be efficient if a large amount of data is collected over large and/or difficult to access areas. The combination of these spacecraft techniques (remote and *in-situ*) results in complementary data since data collection platforms can be used for specific quantitative measurements and where water-body size is smaller than the resolution capability of the remote sensors. This concern is of particular importance in river water quality. The near-shore and oceanic monitoring requires fewer parameters to be monitored and the areal extent involved demands the advantages of remote sensing.

The public service benefit potential of the space techniques is certainly large; however, the economic benefits would be indirect. No negative effects are known unless ocean surveillance becomes a topic of controversy internationally.

It is anticipated that remote sensing space systems for the Prediction of Global Crops, Water, Large Scale Weather, and Global Marine Weather Objectives will provide the type of remote observations (temperature, salinity, water color, turbidity, chlorophyll) required for this Objective using planned instruments. Additional research is needed, however, to define detailed data requirements and accuracies. Considerable effort will then be required to improve techniques for the quantitative measurements of such parameters as chlorophyll and turbidity to the required accuracies. Particular problems are anticipated in turbid coastal waters. Salinity measurements from space of adequate spatial resolution will require large antennas if passive microwave systems are used.

The data collection platform and spacecraft data relay technique have been proven. Therefore, immediate usefulness rests on the availability of *in-situ* sensors to make the desired measurements. More research is required for these sensors, especially in measuring heavy metals, pesticides, and volatile organics.

Developmental achievements prior to operational systems capability include, in summary, the following:

- Detailed data requirements, especially for remote sensors
- Improvement in techniques for quantitative measurement of chlorophyll and turbidity
- Development of large passive microwave antennas to obtain adequate spatial resolution of salinity measurements
- Development of *in-situ* sensors for the measurement of heavy metals, pesticides, and volatile organics
- Analysis of systems to define economic trade-offs between satellite relay and conventional transmission of data

Objective 026 – Global Marine Weather Forecasting

The purpose of Objective 026 is to provide a global marine forecasting capability for support of maritime activities. The requirements for oceanic bulk transportation continue to grow. The world merchant fleet has been expanding by 2,500 vessels per year for 15 years at ever-increasing tonnage and is expected to continue to grow at 15% per year. U.S. imports and exports by sea amounted to 581 million short tons in 1972, an increase of 27% since 1965. The size of the ships continues to increase. Super-tankers (greater than 200,000 deadweight tons) are the most efficient way to carry oil and even larger ships are planned or projected.

These data emphasize the need for knowledge of those factors affecting efficiency and safety at sea. We concluded that forecasts of marine weather (sea state, surface wind, and temperature) could be improved by satellite surveys every eight hours, and these forecasts could be transmitted through communication satellites. Improvements in space systems and analytical techniques would allow the addition of more information and the prediction of currents. The global aspect of the objective implies a satellite system: the cost of a worldwide system utilizing buoys or ships, of fine-enough grid, would be prohibitive.

Optimum ship routing based on improved forecasting is estimated to result in benefits of 30 to 50 million dollars per year to U.S. trade (Reference 24). Benefits to Canadian Arctic operations and offshore oil production would potentially increase this benefit by a factor of four. Additional benefits would accrue to iceberg reconnaissance and the optimization of ship routing from the North Slope oilfields. The forecasts would provide similar benefits for maritime activities that weather forecasts provide to the general population. The inherent dangers of operating at sea make more accurate forecasts critical. Increasing coastal activities (oil drilling, superports, nuclear power, housing complexes, fishing and recreation) and the potential environmental hazards of very large supertankers, all contribute to the need for marine forecasting.

The global nature of this Objective provides the opportunity for joint participation by various nations. The participation could take many forms, from cost sharing to data reception, analysis, prediction, and transmission for various ocean areas.

An initial operational system could be implemented by 1985. This system would be based on techniques and technology results from R&D satellites currently planned. Four satellites in low-altitude near-polar orbit would be required to provide frequency of coverage consistent with wave and fetch conditions. The spacecraft would be equipped with a radar altimeter, microwave radiometer, scatterometer, and an imaging radar. Measurements would include sea state, surface winds, topography, and temperature. Numerical predictive models involving wave refraction and wind/wave interaction would be required for forecasting. Communications satellites would be needed to transmit the forecast to mariners.

Improved systems may be projected for later in the century. More accurate measurements of sea surface topography would allow measurement and prediction of most major currents. Target improvements include surface topography accuracy of ± 1 cm versus the present 10 cm; sea state accuracy of ± 30 cm versus 1 m; surface winds accuracy of ± 10% of mean versus 20%; and sea surface temperature of 0.5°C versus 1°C. Significant research and development of sensors and/or techniques is required to achieve these accuracies. The modeling and associated computing requirements are estimated to be very large and will require careful analyses.

Summary Observations on Theme 02

- Efforts have been and will continue to be focused toward large-scale long-range numerical weather forecasting in the 1970s.
- Activities from 1980 to 2000 will emphasize:
  - Implementation of GARP results into operational systems
  - Continued measurement and analytical technique improvements
  - Major effort toward the understanding and prediction of mesoscale phenomena – local weather and severe storms
- Primary space activity foreseen in weather modification would be to support experiments particularly as high-resolution systems become available
- Development of a number of space observation systems would appear to provide a significant data base for increased effort on understanding and prediction of climate. Pertinent observations include:
  - Radiation budget
  - Surface radiation
  - Snow/sea ice
  - Polar ice sheets
  - Hydrological parameters
  - Atmospheric gases/particles
  - Ocean dynamics
- Stratosphere monitoring and study is important for health considerations as well as climate and is amenable to space monitoring
- Global marine forecasting systems appear feasible and economically attractive. The accurate prediction of currents will be difficult
- Water quality monitoring from space will emphasize relay of *in-situ* measurements through relay satellites to analysis centers
- The monitoring of critical environmental surface areas will be feasible. The development of supporting analytical techniques for information extraction and correlation, and transfer to users, is critical (see Objective 013, Land Use and Environmental Assessment).

THEME 03: Protection of Life and Property

The protection of life and property continues to be a basic desire of the citizenry and requires the dedication of a considerable fraction of a nation's resources. This function is the partial responsibility of all levels of local and federal governments. The areas in which space systems may make significant contributions or improvements include:

- Increase the detail and improve the certainty of forecasts of local weather and other mesoscale phenomena (e.g., severe storms).
- Improve the capability for monitoring tropospheric pollutants to support environmental quality enhancement programs.
- Provide hazard forecasting (floods, fires, etc.) based on *in-situ* measurements relayed through satellites to prediction centers.
- Implement a worldwide satellite communication-navigation capability.
- Develop earthquake prediction capability.

Objective 031 – Local Weather and Severe Storm Forecasting

The purpose of Objective 031 is to increase the detail and improve the certainty of forecasts of local weather and mesoscale phenomena (e.g., severe storms). On the average, severe storms (hurricanes, tornadoes, hailstorms, and severe local winds) take about 600 U.S. lives each year. Normally, each year the U.S. mainland will experience eight tropical storms (Hurricane Agnes killed 118, caused 3.5 billion dollars in property damage); 600-plus tornadoes (the U.S. lost more than 1.0 billion dollars in the period 1965 to 1969); more than 600 damaging hailstorms causing more than 300 million dollars in property damage, and 800 severe local windstorms for which aggregate damage estimates are not available.

In addition to the cost in lives and damage, economic losses are experienced in a number of operations which could be reduced or prevented by improved short-term (1-6 hour) local forecasting. A saving of 10 to 30 million dollars a year is estimated to result from improved forecasting of this nature for operational support of activities such as commercial aviation (Reference 9). Present mesoscale (or local) forecasts are based upon the local forecaster's semiquantitative analysis of the synoptic-scale numerical forecast; it is highly statistical and has little validity beyond 6 to 12 hours.

Space is the only platform that can provide a continuous watch, instantaneous high-resolution images, and timely data collection. The forecasting of severe storms requires a near-continuous monitoring capability with a resolution commensurate with the scale of the phenomena. Current research efforts include studies of tornado dynamics and kinetics, thunderstorm modeling, statistical techniques for hurricane prediction, and preliminary planning for basic cloud physics studies. A reasonable goal for the year 2000 would be a more certain forecast based upon numerical techniques which might provide high accuracy up to six hours and a decreasing accuracy to a maximum useful limit (due to predictability limitations) of 12 hours. A related activity would involve improving the information content and timeliness of data on current weather (nowcasting) over populated and other critical areas. Mesoscale phenomena by definition tend to be localized and consequently may be less important internationally. Larger mesoscale phenomena, such as hurricanes, are generally not confined to single nations and offer the opportunity for, or require a degree of, international cooperation. The technology and techniques for local weather and severe storm prediction represent a potentially-exportable economic commodity and/or an instrument of foreign aid or policy.

Space also provides a vantage point from which warning messages can be relayed regarding impending natural disasters. Emergency communications can be maintained in spite of the natural phenomena occurring and post-disaster communications can continue in an area where disaster effects have rendered conventional communications impossible. In conjunction with the forecasting and storm sensing, a disaster warning or alarm system is required to provide timely and reliable warnings to the public at large, whether at home, at work, or in transit.

The key elements of local weather and severe storm prediction include developing an understanding of the phenomena; models utilizing grid sizes considerably less than those required for large general atmospheric circuation; "nesting" techniques for utilizing and interfacing with the large-scale models; high-resolution, day and night, image and sounding measurements; and a warning system to alert the populace to the dangers in a timely manner. Three generations of capability are foreseen between the years 1975 and 2000 over that currently provided by present synchronous meteorological satellite systems. The first would involve modifying present instruments to provide resolution more comparable with cyclonic disturbances (100 km), the second will involve satellites equipped with instruments of resolution comparable with thunderstorm scale (10 to 20 km); and finally still higher resolution satellites which would provide nighttime coverage with infrared instrumentation. Such a system could serve multiple purposes for a number of Earth observation requirements. By 1985, the "nowcasting" part of the activity could be complete, an alarm or warning system could be in place, as well as an observation system for cyclonic scale disturbances. It is expected that the geosynchronous observation activity for the mesoscale and large-scale forecasting would tend to use the same system, although possibly requiring additional satellites.

The development of these operational capabilities will require:

- Better understanding of fundamental physical processes occurring in storms
- Development of mesoscale models
- Higher resolution sensor development for use at geosynchronous orbits
- Techniques for rapid information extraction, prediction, and warning dissemination

Objective 032 – Tropospheric Pollutants Monitoring

The purpose of this objective is to develop a capability for monitoring tropospheric pollutants to support environmental quality enhancement programs. The deleterious effects of increasing levels of air pollution brought about by industrialization are well documented. They have led to the passage of laws which set air quality standards that require the development of monitoring and control strategies to achieve the standards. The cost of pollution cannot be accurately assessed. The costs of enforcing pollution standards and of reducing automotive and industrial pollution have been estimated at about 2.5 billion dollars annually.

Programs to achieve air quality standards must include a monitoring capability to (1) assess the magnitude of pollution, (2) determine the need for enforcement action, and (3) evaluate the effectiveness of control measures. What is currently missing is the capability to atmospherically monitor the source and flow of pollutants on a national and international basis. Furthermore, the health and climatic effects, the chemistry, and the true costs of pollution are not adequately understood, in part due to the lack of a substantial time series data base. Repetitive, consistent measurements on a regional to global scale can best be made from space. Space system measurements will complement those made from aircraft and ground stations. Integration of pollution measurements and weather and topographic data in appropriate predictive models can aid in the short-term management of pollution crises and in long-term planning for optimum location of polluting activities. Identification of specific local pollution sources from space is not intended.

Ambient standards have been set for sulfur oxides, suspended particulates, carbon monoxide, non-methane hydrocarbons, nitrogen dioxide and photochemical oxidents. The first tropospheric pollution monitoring satellite will be test flown in 1978. Additional research and development missions are needed to define an operational system by 1990, to accuracies adequate to support operational regulatory requirements.

Additional technology development is needed to:

- Measure other pollutants such as SO_2, NO_x, HC_2, and particulates
- Extend vertical burden measurements to the Earth's surface
- Resolve pollutant burdens in and above the mixing layer
- Improve measurement capabilities over land and in the presence of clouds
- Develop software to interpret the satellite measurements and to relate the data to ground-level measurements and to predictive models.

Objective 033 – Hazard Forecasting From *In-Situ* Measurements

The purpose of Objective 033 is to provide hazard forecasting capability (floods, fires, etc.) based on *in-situ* measurements relayed through satellites to prediction centers. Numerous potential hazards are amenable to forecasting if appropriate measurements are available. Some of these types of measurements may be made remotely from spacecraft, but many are not conducive to remote operations. These measurements may be made *in-situ* and transmitted to forecasting centers manually, by telephone, hardline, or microwave network. An alternate means of transmission would be from the *in-situ* measurement stations, via a relay satellite, to the forecasting centers. This means of transmission will be most effective where large remote areas are involved (forests), the hazard itself is likely to disrupt the transmission (floods), or where the measurement stations are generally difficult to access.

Numerous potential applications exist and each must be evaluated. Two examples include the *in-situ* measurement of forest fire indices and the measurement of precipitation and river stage. Operating cost reduction for the forest fire index system for 10 western states is estimated to be from 2 to 10 million dollars per year, plus some reduction in timber loss which now is two million acres per year, and fire control (320 million dollars in 1970; Reference 25). Substantial savings (10 million dollars per year) have been estimated in certain areas relating to improved flood forecasting systems. The 10 state fire index system would involve 1500 *in-situ* measurement stations. The flood gauges/precipitation stations would number 2,500/10,000 over the 11 forecasting regions of the U.S.

This objective could be pursued by a single data and communications satellite system or by utilization of a number of other purpose space systems such as the meteorological systems. The presently planned Tracking and Data Relay Satellite System (TDRSS) represents an initial data-communication satellite system. A post-TDRSS system uniquely designed for data relay from *in-situ* stations and from Earth observation satellites might consist of one geosynchronous and four polar-orbiting (600 nautical miles) communications spacecraft. The geosynchronous spacecraft would have X-band, laser and several low-gain UHF antennas. The polar orbiting spacecraft would have X-band, laser, and omnidirectional UHF antennas. Data capability would include 200 bits/hour from 55,000 *in-situ* stations and 2 gigabits/sec from other Earth survey spacecraft. The configuration would allow hourly measurements from fixed stations; four hours per day from mobile stations, and continuous reception from Earth observation spacecraft. A key to the operation is low-cost antennas at forecasting centers to obtain data directly from the relay satellite.

Continued systems and economic studies would define areas to be incorporated in the satellite network. Low-cost receiving antennas to be used by regional forecasting centers and reliable *in-situ* sensors are necessary elements of those systems and require demonstration prior to the operational phase.

Objective 034 – Communication-Navigation Capability

The purpose of this objective is to implement a worldwide satellite communication-navigation capability. Aircraft and ocean-going traffic has increased significantly in the post-World War II period. For example, seaborne shipping into and out of the United States increased by about 50% in the last 10 years and almost 200% in Japan. International air travel, in terms of passenger miles, has increased by almost 800% in the last 25 years. Growth in such traffic has placed increasing demands upon communications and navigation systems, but even with improvements, accidents are still on the increase (about 600 ocean-going vessels were lost in the later part of the 1960s).

Traffic is likely to continue to increase markedly as nations become more interdependent. The crowded sky phenomenon is likely to have its counterpart in the sea lanes and mistakes are becoming more costly. A supertanker carrying about 250,000 tons of petroleum requires almost three miles and about 20 minutes to stop. Collisions involving such craft involve losses of hundreds of millions of dollars in cargo and shipping, and also create enormous spills and pollution problems. Development of a worldwide communication-navigation capability, in addition to position information, would allow implementation of collision avoidance, search and rescue, fleet management, aircraft safety, and other cost savings and safety techniques.

Space systems offer a unique capability to provide accurate, economical communications and navigation and position-fix information on a global basis. Ground-based systems lack a total global capability, are unreliable, especially for ships at sea, are not capable of handling projected increased traffic, and have limited search and rescue capability. Application of a worldwide system could result in direct economic benefits derived from collision damage abatement (world annual losses: 2.3 billion dollars), improved ship and aircraft operations (ships at sea are at times out of contact for several days), and lower-cost air traffic control systems. Indirect benefits are derived from search and rescue operations in lives saved (Coast Guard estimate of 400 lives per year) and minimized suffering. A somewhat different, but also important, use of such a system would be to provide accurate position-fix information and communications to mineral exploration teams working in remote and poorly-mapped areas. A U.S.-developed system would have international market potential. Since the system is global in nature, it provides an opportunity for international cooperation.

Technology is presently available to implement a navigation system for large aircraft and ships utilizing satellite techniques. An initial approach might consist of a communications system used in conjunction with a planned Department of Defense program (Global Positioning System – GPS) to provide a total communication-navigation capability. It would be desirable to extend this coverage in the future to smaller ships, boats, light aircraft, and various surface mobile activities. More advanced concepts such as short baseline interferometry, which would allow the communication-navigation function to be accomplished without a large number of satellites, have been proposed and warrant continued study for application in the late 1990s.

The initial communication-navigation system would include low-orbit global positioning system spacecraft currently planned by the Department of Defense, plus a civil relay system consisting of four synchronous spacecraft. The total system would require 24 spacecraft in the GPS system plus four synchronous relay satellites, plus appropriate ground control stations. An initial system could be brought into operational use by 1985 serving the larger ships and systems with both communication and position location and smaller vessels and vehicles with beacons for position location. A later system could employ higher-power communication satellites, thereby providing communication capability to small vessels and vehicles at relatively modest cost. Before the end of the century, a third-generation system is envisioned, using short baseline interferometry techniques which would reduce the total number of spacecraft required to three in geostationary orbit.

Objective 035 – Earthquake Prediction

Several million detectable earthquakes occur yearly on our planet. Of these, the great earthquakes (Richter-scale magnitude 8 or higher) are of the most concern even though they are rare. It is conceivable that hundreds of thousands of people might be killed and billions of dollars of damage done if a great earthquake should occur in a densely populated urban center. The United States has no assurance of continued good fortune. For example, it is estimated that great earthquakes will continue to occur along the San Andreas Fault in California at unknown times, but at an average rate of about one every 100 years. Even relatively moderate earthquakes are of major concern, and these have already occurred near urban centers. The dozens of fatalities and the half-billion dollar cost of the 1971 earthquake near Los Angeles represent a recent case.

Recently acquired knowledge in geology and seismology on topics such as plate tectonics and rock dilatancy provide a framework from which many believe earthquake predictions will become feasible soon.

An ideal earthquake prediction system should provide accurate estimates of location, magnitude, time of occurrence, and character of the ground shaking for each significant seismic event. Furthermore, there should be ample warning time. Until recently, location estimates consisted only of crude designations of zones of probable seismicity; magnitude was estimated as a rough maximum for each zone; time-of-occurrence and warning time have been available only in the form of a frustratingly uninformative average-interval-of-recurrence. Techniques now under development show promise of producing more accurate forecasts with the desired outputs and with warning times that increase with magnitude. The emerging techniques are varied and still controversial, however.

A reasonable goal for routine prediction accuracy in the year 2000 is epicentral locations to within a 100 km^2 area, time of occurrence within 10 days, and magnitude estimates within 0.5 for Richter-scale magnitudes between 5 and 9. These data should also be specified six months or more in advance for regions of high population density. With this forecast capability will come quantitative risk assessment. Under certain circumstances, these risks may be judged to be unacceptably high so that earthquake modification and control may be a desirable goal. Some progress has been made in this area.

The benefits of earthquake prediction capability include reduced risks to the life and health of individuals; greater efficiency in the preparation for and response to disasters, and improvement in international relations through mutual benefits, shared disaster planning, and cooperative monitoring.

Earthquake predictions based on *in-situ* measurements are anticipated to be operational within 10 years. *In-situ* measurements will probably include magnetic field, tilt, seismicity, radon count in wells, and rock electrical resistivity measurements. Satellites may play a role in such systems by relaying measurements from remote stations to prediction centers. The use of satellites would obviously depend on the extent of the network.

Very-long-baseline-interferometry (VLBI) and laser ranging to the Moon and satellites are among the subsystems which can play a role in determining which geodynamic phenomena are important in the earthquake mechanism. Of particular importance are Earth crustal deformation on a global and regional scale, variation in the Earth's rotational rate, and crustal wobble relative to the spin axis. VLBI would allow quasars to serve as a fundamental time invariant angular frame of reference. A very stable reference frame is required because the Earth's crustal deformation rates are only a few cm/year and any seismically-related rotational variations are subtle. Spacecraft and the Moon could serve as auxiliary radio signal and laser beam reflection sources for ground-based instruments. The data from these subsystems would be combined with *in-situ* geophysical measurements (i.e., seismology, gravity, tilt, radon count, hydrology) from initial operational systems to provide the basis for advanced systems.

Objective 036 – Control of Harmful Insects

The purpose of this objective is to utilize remote sensing for the identification and control of disease-carrying insects. The human toll of insect-borne diseases is exceedingly severe, especially in the tropical regions of Asia, Africa and South America. In addition, worldwide food crop losses of 10% to 20% are attributable to insect infestations. Many of these diseases are theoretically controllable, but the difficulties involved are great. Remote sensing is a new weapon of great promise in this field. Biological field work is used to identify the habitats in which insect carriers of specific diseases can be found, the directions and limits of their potential spread, and when and where they will breed. This information can be expressed in terms of such parameters as surface temperature, water temperature or soil moisture, and type and amount of vegetative cover – parameters which can be remotely sensed from space. Thus, surveys from spacecraft can be an invaluable tool to insect surveillance, control and eradication programs.

A pilot program is the current U.S.-Mexican Screwworm Eradication Project. This project is aimed at eradicating the cattle-destroying larvae of the blowfly in Mexico by dropping, from aircraft, sterile male blowflies at the correct times and locations to interrupt the insect's breeding cycle. Satellite data were utilized to develop accurate vegetation maps. Surface temperature data from satellites will be used to time the drops. These services are expected to reduce the necessary coverage by one-third, and the cost of the program by 25%.

If successful, this technique will have immediate application to the elimination of the Tsetse fly, the carrier of African sleeping sickness. Preliminary discussions have been conducted with the Agency for International Development (AID), which is conducting pilot programs involving the sterile male technique. AID estimates that the eradication of this disease, which is of enormous economic importance, will take up to 40 years and cost 1.5 billion dollars. Other programs being studied involve onchorercioses ("river blindness") along the Niger River, locust swarms in the Red Sea area, and mosquito-borne diseases in the southern U.S. Certain agricultural insect pests, such as the cereal leaf beetle in the U.S., are amenable to control by similar techniques. The insect vector control methods are feasible, and can provide a significant and worldwide public health service. The technology is that of earth survey spacecraft coupled with insect characteristics-environmental relationships. Other systems cannot provide the large area coverage required except at considerable expense and time. A successful system will improve world food supplies by improving animal health, opening up new arable land, and assisting in control of agricultural insect pests.

No unique space systems are envisioned for this objective. The technical requirements for potential applications can be met by systems described for Crop Prediction (Objective 011), Water Forecasting (Objective 012), Large Scale Weather and Severe Storm Forecasting (Objective 021 and 031). High spatial resolution and daily measurement are required for some applications. The data reduction and modeling software systems will require continued inter-agency and inter-governmental cooperation and have a degree of uniqueness for each application.

Summary Observations on Theme 03

- A major effort toward prediction of local and severe weather is warranted
    - Intense study of phenomena required and underway
    - Geostationary, high resolution capability required and will evolve
    - Associated "alarm system" using communication satellite technology is feasible
- Initial measurement of tropospheric pollutants is now planned. Additional R&D required for the type of measurements and accuracies is required. Operational systems in support of regional management activities are not foreseen until the late 1980s.

  - Remote sensing from space offers selected opportunities to provide environmental information leading to the control and/or eradication of certain harmful insects
  - Hazard forecasting systems for forest fires, floods and similar disasters based on *in-situ* measurements and data relay through satellites will increase as determined by economics and new *in-situ* instruments
  - Earthquake prediction based on *in-situ* measurements is anticipated within the decade. Satellite measurements (dilatancy, plate motion) may provide information for the understanding of the phenomena and definition of advanced systems
- Technology for initial communication-navigation system (possibly in conjunction with a DOD global positioning system) is available. Future thrust will be to reduce cost/complexity of surface equipments and subsequently to reduce the number of satellites required.

THEME 04: Energy and Mineral Exploration

As Chapter 4 has shown, the demand for natural resources, especially energy resources, is growing very rapidly and the trend can be expected to continue. One important energy source – water for hydroelectric generators – has been discussed. In the paragraphs that follow, we consider mineral exploration both as an energy-producing activity – e.g., coal, petroleum, and fissionable materials – and as a quest for materials for other purposes. We also consider energy sources other than minerals and flowing water – e.g., the Sun. In addition, the potential of space as a disposal area for nuclear and other hazardous waste is discussed.

Activities discussed in other themes which also contribute to this theme are: Water Availability Forecasting (Objective 012), monitoring energy-related environmental effects, and satellite navigation networks.

Objective 041 – Solar Power Stations in Space

The purpose of Objective 041 is to develop a solar power station(s) to provide a significant portion of the nation's energy needs. The large consumption of energy is a characteristic and requirement of industrialized societies. While it is possible to improve the efficiency of the extraction of energy resources, their conversion, transmission, storage, and consumption, there will continue to be an increasing need for additional energy supplies. While there have been significant short-term variations from the general trend, the overall growth in U.S. energy consumption from 1850 to 1970 has resulted in an increase from about 2.5×10^{15} BTU/year to approximately 68×10^{15} BTU/year (a 27-fold increase in 120 years). During the 25-year period between 1947 and 1972, the total energy consumption in the United States increased from 33×10^{15} BTU to 72×10^{15} BTU.

In 1850, the main source of energy was wood. By 1884, the consumption of coal equaled that of wood and continued to increase until it became the dominant source of energy in the United States. Petroleum was introduced before 1900, surpassed wood in 1917 as a energy source, and equaled and surpassed the consumption of coal in 1950. The use of natural gas surpassed coal by 1958. Use of hydroelectric power, while small, has contributed to the energy supply since 1900. Nuclear energy, introduced in the 1960s had not yet reached the one percent contribution by 1970, still made by wood as an energy source. Nuclear sources are presently increasing their portion of the energy supply in the United States. While the total energy consumption in the United States has increased, the growth in the use of electricity of 7% per year has been even greater. The total installed electric utility generating capacity in the United States was expected to be 480,000 MW by the end of 1974, according to one reference.

In recent years, our needs have been met primarily by oil and natural gas. For example, in 1970, 82% (24.4 million equivalent barrels of oil per day) of total usage consisted of oil and natural gas. Only 16% (3.9 million equivalent barrels of oil per day) of the oil and gas, or 13% of the total energy used was imported (Reference 11).

This may be contrasted with information provided in a recent Presidential speech which indicated that foreign oil now represents 37% of current usage. The growth in imports relates not only to our increased usage, but the rapid depletion of known domestic reserves. An AIAA publication on "Solar Energy for Earth" (Reference 26) shows that the ratio of reserve to production of natural gas dropped from 16 years to less than 10 years between 1966 and 1973, and the same ratio for oil dropped from 13 years to less than seven years in the 1955 to 1973 time period. While the domestic supply has been significantly augmented by imports as indicated above, even these reserves are also limited. Much of the rest of the world is now consuming energy at a growth rate greater than the U.S. and it is expected that the world as a whole will use as much energy between 1970 and 2000 as it did for the total period of time up until 1970. More specifically, a mere 2% worldwide growth rate (versus current 5.7% U.S. growth rate) will result in an exhaustion of oil and gas in a few decades. Many more statistics can be quoted from various sources but all trends point to a requirement for significant sources of energy other than oil and natural gas in the near future.

Alternate sources of energy include coal, nuclear fission, nuclear fusion, solar, hydroelectric and a few others, such as geothermal sources and tides, which are not expected to make significant contributions.

The contribution of coal in meeting our energy needs can and probably will be greatly expanded. A tripling of coal production by the year 2000 might be possible considering its resource base. This would provide the equivalent of 20 million barrels of oil per day but still no more than about 20% of a projected need of 80 to 120 million equivalent barrels of oil per day. The availability of water, reclamation problems, fabrication considerations of the massive equipment required, steel, transportation facilities, and other such items might make this projection optimistic. While coal would continue to make a significant contribution to national and world needs beyond the turn of the century, current estimates indicate that it would be exhausted in one to two centuries.

A number of the possible energy sources have significant environmental problems. The use of fossil fuels contributes to air pollution and longer term environmental degradation. Problems associated with strip mining and oil spills are well known. Particulate concentrations have been increasing, but particulate emissions from combustion sources can be controlled by a variety of devices. The longer term effects are generally expected to result from the increase of carbon dioxide in the atmosphere. Means of removal are not apparent and increases will continue as long as fossil fuels are used.

While several studies have predicted a doubling of atmospheric CO_2 by the year 2000, with resulting increases in worldwide temperatures and associated catastrophic effects, more conservative studies estimate the possibility of a 0.5°C increase in average Earth temperature, with regional changes of 1.5°C (Reference 20). Even this apparently modest increase would almost certainly cause changes in atmospheric circulation patterns with resulting changes in rainfall, leading in turn to significant effects upon food production which could be catastrophic in currently marginal areas. Extension of these trends into the next century would almost certainly result in significant changes.

The nuclear fuel option as an alternate to oil and natural gas is one that the nation is heavily committed to at the present time. While in 1970 its contribution to the nation's energy needs was insignificant, one projection would indicate that nuclear fuel will contribute almost one-third of the nation's needs in the year 2000. This projection is somewhat less than the maximum capability that has been projected for this time period. The development of nuclear fission is proceeding in two phases. The fission burner reactor is fueled by the scarce U-235 isotope or the man-made plutonium and U-233 isotope. The fission burner reactor, however, represents a relatively short term energy solution because the available resource will be consumed shortly with the greatly expanded projected use. Nuclear power plants are suffering from rapidly escalating costs. For example, the investment costs of light water reactor plants have about doubled between 1967 and 1973, independent of inflation increases (Reference 27).

Despite the fact that about 300 such reactors were operating, under construction, or on order, the industry has not yet learned enough to reduce capital costs. Thus, the future costs of nuclear power plants cannot be estimated with great confidence. These relatively high and/or increasing costs are due in part to safety features and associated regulations and reviews. These actions in turn apparently mirror a continuing and growing public concern with safety and environmental hazards.

The fission breeder reactor is not natural resource limited as the fission burner reactor; however, it is even more controversial since its plutonium fuel is extremely toxic and exceedingly dangerous if it falls into the hands of irresponsible parties.

Nuclear fusion potentially and ultimately represents a most suitable energy source in terms of safety, environment, efficiency and economy. Its technical feasibility, however, remains to be demonstrated, and such demonstrations are not expected until the 1990s.

The long-term effects of increasing the carbon dioxide in the atmosphere were discussed earlier in relation to fossil fuels. While nuclear power plants would relieve this situation, the use of either fossil fuels or nuclear plants would contribute significantly to the direct heating of the atmosphere with a resulting concern for climatic effects. William W. Kellogg (Reference 20) has estimated possible increases in the average Earth temperature by as much as 1.3 to 3°C, based on a world population of 20 billion in the twenty-first century with a per capita annual use of 40 kilowatts (Reference 20). Such an increase in average Earth temperature could very well result in 10°C changes at the poles with the possibility of melting the Arctic ice pack and in turn causing significant precipitation effects in the northern regions.

Hydroelectric power has already been developed to a large extent in the United States and even more so in Europe. In the northeastern region of the United States, more than one-half of the available hydroelectric power sites have been exploited, but further development may involve environmental dislocations. While some increase in hydroelectric power is possible, this source of energy cannot contribute substantially to the increasing demand for energy in the United States.

The foregoing discussion and projections related to fossil and nuclear fuels and hydroelectric power have attempted to show that, while they will contribute to varying degrees to our energy needs, it has not been demonstrated that they represent completely satisfactory solutions to our energy needs as we move into the 21st century. Consequently, it is considered prudent to consider the use of solar energy to augment our other supplies in the mid-term future (21st century) and possibly to contribute a significant portion of these needs in the distant future. The Sun itself represents a clean and virtually unlimited source of energy. The capture and conversion of the solar radiation into useful forms of energy offers its own questions in regard to feasibility, economics, and environment. Many variations on the use of solar energy have been studied. We will address two basic variations here. The first deals with the collection of the solar radiation on the Earth's surface, and the second deals with the collection of the radiation in space and transmission to Earth in microwave form.

Low-temperature flat-plate type of solar energy collection for hot water and space heating and space cooling is well known. The degree of its use will be dictated to a large extent by the economics and availability of other systems. It also requires supplementary energy sources for nights and periods of low solar radiation since it appears economically impractical, even with energy storage capability, to provide all heating and cooling needs. Certain projections indicate that this technique may provide 1 to 2.5% of total energy required in the year 2000, based on 1973 estimates of future fossil-fuel prices (Reference 26).

Solar thermal electric power involves the conversion of solar radiation into thermal energy and then into electric power. No significant technology barriers exist to the development of such systems with intermediate loads, central receiver systems being favored. The primary limitation upon this system relates to the need of large storage capacity to accommodate the day-night cycle and periods of reduced solar radiation. Costs increase rapidly with storage capacity requirements and a trade-off between the size of this capacity and supplementary alternate supplies of energy is required. While the technology exists for this approach, its viability and degree of use is an economic consideration as well as a consideration of construction time and huge size, i.e., 250 acres per 100 MW of power.

An alternate to the solar-thermal conversion system would be the use of solar cells to directly convert the solar radiation to electric power. The technical feasibility of such an approach is well established through space program activities. Economics will be one deciding factor in the extent of terrestrial use of photovoltaic systems.

Terrestrial versions of space systems cost about 20 dollars per peak watt; consequently, cost reductions of a factor of 100 to 1000 are required to make this system cost-competitive. The photovoltaic systems are relatively flexible in size which provides a significant advantage. Conventional fossil fuel, nuclear, and solar thermal systems are all much more sensitive to size and generally need to be large to be economical. The photovoltaic systems can be co-located with their loads, thereby avoiding a degree of capital costs and transmission power losses.

The terrestrial photovoltaic system, however, suffers from the same basic problems as the solar thermal electric system, namely the day-night cycle, clouds, varying seasonal radiation conditions, and some atmospheric degradation. Some of these effects vary greatly with geographical locations. The optimization of geographical locations relative to use requirements inevitably results in increased transmission considerations and costs. The normal approach to the variations in available solar radiation is the use of storage system and alternate sources. The addition of these elements of a system rapidly increases the cost of the system.

A basic approach to gaining the virtually inexhaustible energy of the Sun without being hampered by the problems described above would be to place the power station in space above the atmosphere, and in geometrical relation to the Sun so that it can collect power nearly 24 hours a day. Such a location increases the ability to collect solar radiation by a factor of six to 15 times as compared to an equivalent terrestrial system. While the basic advantages of locating the power station in space are obvious, many difficult problems would have to be overcome before such a system could contribute significantly to our energy requirements.

Initially, the technological feasibility of the system must be established. Conceptual approaches have been generated for both photovoltaic and solar-thermal-electric systems. While it is probably feasible to build such a station, the question is whether it could be done in an economically viable manner. Based on today's estimates, one approach would require the cost of solar cell arrays to be reduced by as much as two to three orders of magnitude. These economic factors will obviously vary with the changing costs of competitive systems, i.e., nuclear, which, as noted earlier, have shown a trend of significantly increasing costs.

In view of the well-documented criticality of the energy situation, and the fact that all proposed solutions have problems to some degree and offer advantages of varying kinds, it is believed that solar power stations should be investigated carefully as to their ability to provide a significant portion of the nation's energy needs with an initial capability by the end of the century.

Several design approaches to satellite solar power stations have been considered in conceptual studies. The two receiving the most attention to date have been the solar photovoltaic and the solar thermal approaches. It should be emphasized that the studies done to date have not provided a basis for selection of a design approach. The following paragraph presents information on the photovoltaic approach, but only for the purposes of illustrating some of the technical factors involved in implementing the objective.

Primary elements of a conceptual operational system include a large array of solar cells (50 km^2), with a microwave transmitting antenna (1 km^2) located in aerostationary orbit and weighing of the order of 25 to 50 million pounds. The space element is complemented by a ground receiving antenna of the order of 100 km^2. In order to transport the large station(s) into space, a vehicle capable of placing hundreds of thousands of pounds to low Earth orbit at a cost per pound much less than those anticipated for the Shuttle is required. An additional propulsion device is required to move the assembled or semi-assembled station to geostationary orbit. There is an implied requirement for manned activities in low Earth orbit related to assembly and a degree of manufacturing, and more limited activities at geosynchronous orbit for power station initial operation, monitoring and maintenance.

In order to achieve the overall goal of implementing a significant number of stations in the first half of the 21st century, it is necessary to initiate operation of a first large scale station before the year 2000. This station might be somewhat less than "full-scale" (5000 MW) but would be of a scale sufficient to demonstrate all aspects of the system, and capable of augmentation to reach full capability.

It is estimated that the commitment to this first station would need to take place in the mid-1980s. This would allow the necessary time to complete final design and development of the major elements of the system. In order to prepare for the necessary decision in the mid-1980s, an intensive program of activity is required in the 1975 to 1985 time period. This program would require a number of elements:

1. Ground technology development of the various elements of the power station to achieve the necessary efficiencies and cost.
2. Transportation system analysis and associated technology developments to define systems of achieving the low-cost-to-orbit efficiencies required.
3. A continuing series of overall systems analyses to guide the ground technology, to define the space test program, and to provide the necessary technical inputs to allow the comparative economic and environmental analyses.
4. A space test program to develop or demonstrate various elements of the program which cannot be adequately conducted on the ground. This program will include the assembly of large scale structures and their subsequent dynamics, related manned and automated operations, and exposure of various equipments and operations to the environment of space.
5. A continuing program to study the merits of the proposed system in relation to competitive approaches, including economic, social, environmental, and technical status.

Particular areas that will require study and/or development include:

- Large, low-cost transportation system
- Advanced space upper stages
- Extensive operations in space for long periods
- Large, lightweight non-rigid structures and materials
- Pointing of such structures
- Solar cells
- DC-RF conversion
- High voltage-plasma interaction
- Reliable techniques for assembly of radiator systems
- Rotating machinery long-term maintenance and reliability
- Microwave effects on humans
- Microwave beam – ionospheric interaction
- Radio-frequency interference
- Economics

Objective 042 – Power Relay via Satellites

The purpose of this objective is to develop the capability to relay large amounts of power over long distances via satellite relay. With the growing worldwide demand for electric power, there is a possible need to remotely locate power generating systems at the site of energy resources, as in the case of desert-located solar power stations, or new fossil fuel deposits, or as a result of environmental considerations for nuclear power stations. The remote location of nuclear power stations would include possible location in space as well as unpopulated places on Earth. Such a location (space) for nuclear power stations might provide additional benefits, such as easier disposal of hazardous waste to deep space.

A power transmission/distribution system based on a wireless microwave power transfer technique offers some unique and potentially beneficial characteristics. The microwave power transmission technique, coupled with a power relay satellite, offers an opportunity to transport large quantities of electrical energy from relatively remote power generation centers to local users. Conventional techniques such as power lines incur losses which are proportional to transmission distance.

The economic benefits of such a relay satellite system depend directly on an established need to move large amounts of power over long distances. This system would be in competition with all forms of power transmission from energy in raw form such as coal, oil, etc. as well as conventional electric power transmission. If the

U.S. were to develop an excess power capability, thus creating an exportable commodity, a power relay satellite system would permit power transmission across oceans to potential customers. Since the power transmission system is an integral part, by and large, of the solar power station concept, the technologies are mutually supportive. The power relay system, however, has a uniquely difficult problem in relation to the very high pointing requirements of the reflector element of the system.

A power relay system consists of an Earth-based microwave generation facility which converts electric power to microwave energy, an antenna which transmits the microwave beam to a power relay satellite located in synchronous orbit, where the beam is passively reflected toward an Earth-based receiving antenna, and a microwave receiver where the microwave energy is rectified to produce electricity. Although smaller than the Space Power Station, it is still a large space system (1 to 2 km space reflector). A possible development schedule might be as follows:

During the 1975 to 1985 time period the necessary research and development required for the system could be accomplished. A critical technology item is associated with the pointing of the space system. With the exception of the solar cells or other energy collecting system, the power relay system would require developments similar to the solar power station, with somewhat less size and weight involved.

The development and implementation of a prototype system might be completed in the 1985 to 1993 period and an operational system could be in use in the 1993 to 2000 period.

Objective 043 – Hazardous Waste Disposal in Space

The purpose of this objective is to develop and implement a capability to dispose of large quantities of hazardous waste outside the solar system. Current discussions about ways of providing U.S. energy needs indicate that about 50,000 quadrillion BTU of energy annually may be supplied by nuclear power stations in the year 2000. This would represent about one-third of the total supply at the time, up from an insignificant level in the early 1970s. Tons of nuclear waste products would be generated annually under such conditions. Worldwide growth in nuclear power stations is likely to follow similar trends. Since the radioactive half-life of these waste materials is measured in thousands of years, safe means of disposal must be found. These means can only consist of permanent, impermeable encapsulation for storage on (or in) the Earth, or disposal in space away from the Earth, preferably outside the solar system. The latter would involve safety considerations in the launch process but a competitive risk situation exists when the hazards of Earth storage are considered.

Space beyond our solar system offers an unlimited potential for permanent safe storage for nuclear waste. These materials with long half-lives would no longer present hazards to future generations on Earth. As the worldwide use of nuclear energy increases (1,000,000 MW in the U.S. alone by 2000), public safety assurance relative to nuclear waste disposal will become increasingly difficult using Earth-storage techniques, which will constitute a degree of public hazard for centuries.

The overall system to pursue this objective would include a ground-based waste separation/concentration system and a space system with a shielded, impact-survivable container, and a solar escape transportation system. The Shuttle plus an upper stage could provide adequate, economic, and safe transportation for waste disposal. The large number of launches required may make an optimized design launch vehicle desirable. Concentration ratio capability is the key economic driver and would require research and technological advance. It is expected that the necessary developments, including a remote launch site, could be completed during the 1980s in order to handle the rapidly increasing wastes expected during that decade.

Objective 044 – World Geologic Atlas

The purpose of this objective is to provide a world geologic atlas to support mineral exploration and development planning. The world's consumption of important minerals has increased more rapidly than the population, which has grown by a factor of almost 2.5 since 1900, and mineral consumption is likely to increase by another 70 or 80 percent by the end of this century. For example, in the United States, both aluminum and nickel consumption more than tripled during the 1950s and 1960s. Known reserves of many critical materials, including copper, lead, tin, zinc, tungsten, barite, mercury, and silver, range only up to 25 years and significant proven reserves have not been found since 1950 for many of these materials, including lead, zinc, manganese, tin, and tungsten. In order to support and encourage increased mineral exploration, it is proposed to prepare or update general geologic and tectonic maps for selected areas of the world at a scale of 1:250,000, special purpose maps (e.g., selected lithologies, known mineral deposits) and photomosaics of land areas at 1:1,000,000 scale, using space-acquired data to complement existing data. The areas selected would be those that have been least explored and mapped to date and where conditions exist such that the U.S. might benefit from improved and increased mineral exploration in the area.

The pursuit of this objective would require no unique space system; all requirements could be met by those systems required for Crop Forecasting (Objective 011). Increased imaging resolution over current capabilities will provide interpretation capability in difficult areas. Imaging radar would provide additional capability in heavily vegetated and/or cloud covered areas. Specific surveys from the Shuttle could provide coverage of particularly difficult areas, at least within Shuttle performance capabilities. The technical risk is small in arid to semi-arid regions, and substantial in populated and vegetated regions. Existing map coverage varies greatly. Thirty percent of the U.S. is mapped to a 1:250,000 scale. Canada and western Europe are well mapped. Mexican mapping is being improved. Mapping of Africa, Middle East, and South America is extremely variable. This objective would require a continuing long-term effort, with the rate of progress being directly proportional to resources allotted for technique development, interpretation, and map preparation. The pre-operational requirements include:

- Selection of priority areas of interest
- Continued optimization of techniques for extracting geologic information from space data
- Increased resolution over current satellite imagery for interpretation capability in difficult areas
- Imaging radar to provide a capability in heavily vegetated and/or cloud covered areas.

Space activities in other themes which benefit this theme for energy and mineral exploration include:

- *Objective 012:* Provision of forecasts of water availability for irrigation, *hydroelectric power generation, and shale cracking* based on spacecraft surveys of snow and moisture.
- *Objectives 013, 024, 025, 032:* Monitoring of energy-related environmental effects on land, in water, and in the atmosphere, using remote sensing from space and/or relay satellites for *in-situ* measurements.
- *Objective 034:* Implementation of a worldwide satellite communications-navigation capability which would include an accurate position-fix and communications capability for field parties exploring in remote areas.
- *Objective 071:* Regular surveys of the Earth's magnetic field which would provide a reference for local high resolution surveys.

Summary Observations on Theme 04

- Space system possibilities may contribute to generation, transmission, environmental protection, and aid to mineral exploration.
- Space solar power stations represent a potentially important contribution to energy needs; however, economic and technological feasibility have not been established at the present and should be vigorously pursued.
- The need for satellites for Earth point-to-point relay of power appears marginal at present, coupled with difficult pointing requirements.
- Nuclear waste disposal outside the solar system appears feasible and economically viable. Public reaction and potential alternatives will determine acceptance.
- Earth observation systems can contribute to the optimum siting of new power plants, strip mining monitoring, the monitoring of water and atmospheric pollutants from such plants, and the longer term effects of these pollutants on the atmosphere (see the Themes 01, 02 and 03).
- Mineral exploration can be aided by the availability of global imagery to develop geological maps, reference magnetic surveys, and mobile position determination.

THEME 05: Transfer of Information

The last two decades have seen a revolution in the transfer of information which is continuing and accelerating today with the advances in microelectronics and information technology. The volume of personal and business telephone communication via satellite has grown steadily and the potential of this field for increasing the efficiency of human activities on Earth, and for alleviating age-old problems of isolation in some parts of the world, is very great. In the three objectives under this theme, we discuss some of these possibilities.

Objective 051 – Domestic Communications

The purpose of Objective 051 is to provide a domestic communication satellite network capable of providing the growing information transfer and service requirements of the 1990s. Requirements for the transfer of information have been growing at a rate of 15 to 20 percent per year and there is reason to believe the trend will continue. This increase can be related to population, industrialization, trade and economic interdependence, and developing nations. Communications satellites are an established element of the total communication system. Intercontinental communication by satellite was the first space activity to be commercialized in a major way. Satellites are now beginning to carry a portion of the domestic traffic. The following satellite characteristics were recognized early and the opportunities have been capitalized on by the U.S. to a considerable degree:

- Satellite links are more reliable because there are fewer cascaded elements between the end-points of a link.
- For a given satellite coverage zone, cost of a link will be independent of the distance between Earth stations.
- Satellite links do not cross national boundaries as do cable systems. This simplifies tariff problems; that is, the links can be point-to-point.
- Satellite links can eliminate outages due to local weather, disasters, and political disorders.
- High-capacity satellite links can be quickly and easily provided into underdeveloped countries where cable systems do not exist (or are inadequate) by installing a mobile or transportable Earth station.
- Satellites are advantageous for maritime communications since they can cover entire oceans, providing instantaneous high-quality communications to vessels at seas.

Satellite systems and cable systems are mutually complementary, and together they provide flexible, reliable, and minimal cost international/intercontinental communication, with reserve capacity and capability for alternate routing.

More recently, domestic communication satellites have been introduced into operational use, and additional systems are expected in the foreseeable future. A number of foreign nations are now proceeding seriously with domestic or regional systems. While such foreign activities will expand the use of space technology, they will also introduce a significant degree of competition for expert opportunity for the U.S.

The use of communication satellites has been extended to radio, television, and various commercial communication activities. The benefits of satellite communications to other applications such as health care and education are being realized; with communications to 10-foot diameter antenna stations in diverse locations to provide public services to individuals. The trend indicated is that satellite technology not only will provide communications independent of distance, but also independent of fixed receiver sites. Ultimately, the individual subscriber will be able to access a variety of communication services – entertainment, disaster warning, computer processing – from a low-cost portable terminal similar to a telephone anywhere in the United States.

Intercontinental communication satellites have been used extensively for television transmission. Present domestic satellites have the capability for television but have not been used for the purpose as yet. Direct broadcast television, while technologically feasible, remains a question of economics.

The use of satellites for special functions is in an active experimental phase and should increase significantly in such areas as teleconferencing, electronic mail, computer interconnection, health care, emergency guidance and medical proficiency maintenance in rural areas, records transfer, and rural or remote educations.

An increasing requirement for conventional communications, and a growing need for communications services by the general public, industry, educational institutions, and government necessitates expansion of current domestic communication capacity. The annual growth rate in domestic communications is 5% for local telephone calls, 10% for long distance, 15% for new households using Cable TV systems, 10% for increase in volume of checks transferring funds, and 3% for increased mail volume.

Recent experience with domestic communications satellites indicates that services offered by satellites are competitive with land-line systems, particularly for distances exceeding 200 miles. Satellites offer a flexible and cost-effective means of meeting increased demands (19% per year growth rate of satellite communications), while at the same time creating a competitive environment which has resulted in reduced rates to consumers. Estimates indicate a need for as many as 40 domestic satellites by the year 2000 for worldwide service. Development of a standardized satellite system may be desirable to minimize consumer service costs while creating an internationally competitive satellite system for use outside the U.S.

The U.S. is currently a world leader in communications satellites, but that position is being challenged by both Europe and Asia, where industry and government are working together to compete with the U.S. in order to meet the challenge. A new technological stimulus appears in order in the U.S. A substantial subsystem research and development program is required. Currently, data transmission rates via satellite are about 200 megabits/sec with a required growth to 1000 megabits/sec over the next few years. Satellite frequency band crowding at the lower frequency (4 to 6 GHz) will require exploitation of the higher bands to keep pace with the communication demands. The 12 to 14 GHz band will be used in the next several years for certain satellite communications, however, the higher frequency bands (18 to 30 GHz and higher) offer the broad bandwidths necessary to accommodate expected demand. In addition, multi-spot beam antennas with up to 50 spots per antenna will be required to accommodate the multiplicity of communication users, particularly for point-to-point modes. Antennas today have three-to four-spot beam capability. The multi-beam technology is also necessary for contoured beam shaping. High gain antenna systems are necessary to utilize the higher frequency bands.

Presently the highest power amplifiers for spacecraft use are limited to 200 watts or less. As large numbers of new satellite communications users enter the scene (direct broadcast, mobile communications, personal communications), powers approaching 1 kilowatt will be necessary, with several kilowatts per spacecraft probable by the end of the century.

A conceptual communications system design to meet the domestic needs of the 1990s might include a spacecraft weighing 550 kg, with 2 kw of prime power and 30 active transponders plus the complementary ground stations. The worldwide system would comprise an estimated 20 U.S. satellites and 20 foreign satellites. Satellite-to-satellite link capability would be included. Although present terrestrial systems provide good national coverage with narrowband service (voice channels) and limited broadband service, the new system would provide national coverage of broadband as well as narrowband service with high power satellites, thus allowing use of low cost ground systems. All follow-on improvements would be aimed at lowering consumer cost. Key technological advances prior to the operational phase would be in high-power amplifiers and large multibeam antennas, including their assembly and deployment.

Objective 052 – Intercontinental Communications

The purpose of this objective is to provide an intercontinental communications satellite network capability to provide for the increasing information transfer needs of the 1990s. International and intercontinental communications are increasing in importance as world interdependency and required communications between countries grow. As evidence of this, overseas telephone volume was expanding at the rate of 30 percent per year in 1970 with indications that the rate of growth is increasing. In 1950, the growth rate was only 15 percent per year. The introduction of satellites contributed to the growth rate by making rate reductions possible, thereby stimulating usage. The growth in the field of data communications to service multi-national corporations adds to the increase in the demand for services.

Satellites are ideally suited for the service demand contemplated because of their route structure flexibility in point-to-point communications links. Capacity between points can be varied with demand, thereby increasing the cost-effectiveness of the service offered. Satellites permit worldwide point-to-point communications without violating national boundaries. In conjunction with cable systems, they provide a reliable, flexible, low cost system.

Satellites in the International Telecommunications Satellite (INTELSAT) system have provided an opportunity for developing nations to establish, within their ability to pay, first-class communications with the rest of the world. An active role by the U.S. in the development of satellite systems for international service will help maintain a leading position in this high technology market. U.S. systems result in direct revenues and jobs in the U.S. by enhancing our international trade position. Continued dominance in this area will help maintain the U.S. image as the leading high-technology systems exporter. Competition in the communications satellite market is growing, however, as is evidenced by the increased activity in satellite development in both European and Japanese industries.

The following conceptual system design and associated research and development activity are aimed at meeting the estimated international communications requirements of the 1990s. A projected operational system for that period would include 12 satellites in geosynchronous orbit, six over the Atlantic, four over the Pacific and two over the Indian Ocean. The satellites would weigh about 2000 kg and have a prime power of 3000 watts. Their 30 transponders would provide broadband service for video, voice, and data information. Improvements over present satellite/cable systems are related to lower operational costs, broader world coverage and multi-purpose operation. Technological advances are focused on high-power RF systems, large multi-beam antenna systems, and satellite-to-satellite links with lasers and/or millimeter wave systems.

Objective 053 – Personal Communications

Another desirable objective, although not considered currently economically feasible, would develop the necessary technology for, and provide a first comprehensive demonstration of, satellite-provided personal communications service. "Personal communications" would permit individuals to communicate with others regardless of the location of either. The technology program would be aimed at providing system and hardware designs that would be economical to manufacture, reliable, efficient in use of power and bandwidth, and attractive and easily used by non-technical consumers. The technical obstacles are many but solvable: high-power transmitters and very sensitive receivers are needed; frequency spectrum reuse will require multi-beam antennas; and onboard routing and switching will most likely be required. Maintenance of privacy is also a special requirement in many cases.

A demonstration project could employ a satellite to provide services to a selected user population for a period of one to two years.

We believe that once the capability was demonstrated, industry would capitalize ventures to provide these services. If the past trend of technology dissemination continues, these services would first be purchased by government, then business people, then individual consumers in an ever-growing market. In the United States and overseas, millions of people could be using these services by the year 2000.

The key phases in achieving the objective involve mission design studies (1980 to 1984); development initiation (1985), and initial operations (1988 to 1990). The development period would be aimed at establishing service demand, satellite system requirements to provide personal communications, terminal economics studies, propagation studies, and regulation and policy impact studies. Initially, the effects on a selected service population would be evaluated for one or more years to assess market demand for private industry, who would be expected to establish the subsequent commercial services.

Summary Observations on Theme 05

- Growth projections indicate a potential need for intercontinental and domestic communication networks of the order of 12 to 40 satellites, respectively, by the year 2000.
- These satellites will require transmission links of higher data rate and higher power, increased bandwidth, larger and more sophisticated antennas, and improved attitude control.
- Communication satellite experiments have demonstrated utility in meeting specialized needs (education and health care) for remote and rural areas.
- Emphasis of foreign countries on development of communications satellites will challenge U.S. leadership and affect associated economic benefits to the U.S.
- Federal government participation in communication satellite research and development and demonstration might be desirable to provide new stimulus to private industry.
- Direct TV broadcasting is feasible but its implementation is dependent upon economic and present investment considerations.
- Personal communications through satellites are yet to become economically viable and will require significant technological advance.
- Existing communications technology provides the basis for a variety of hazard (forest fires, floods) and environmental monitoring systems. Economics, *in-situ* sensor technology, and reliability will govern degree of implementation (see Themes 02 and 03).
- Household alarm of impending disaster, storms, etc., is feasible and probably economically viable (see Theme 03).
- Satellite-based navigation systems for larger ships and aircraft are feasible today. High powered satellites would allow extension to smaller boats and other mobile devices on an economic basis (see Theme 03).

THEME 06: Use of the Environment of Space for Scientific Commercial Purposes

The environment of space offers a near-zero-gravity environment, a hard vacuum and radiation unaffected by the Earth's atmosphere. A number of activities benefiting from access to this environment, particularly zero-gravity have been considered. These include basic physics and chemistry experiments, research in materials science, the potential of commercial inorganic processing in space, and the production or isolation of biological materials by processes which require weightlessness. The study of the effects of gravity on the evolution and forms of terrestrial life as well as the effect on human beings living and working in space for extended periods of time are also included in this theme.

Most, if not all, of the activities of this theme require, or would greatly benefit from, human activity in space. Furthermore, while a considerable amount of preliminary work can be accomplished with short-duration stays in space using Spacelab, full accomplishment will require long duration stays in some sort of space station facility.

Objective 061 – Basic Physics and Chemistry

The purpose of Objective 061 is to perform basic and applied physical science laboratory-type experiments which require the space environment, primarily weightlessness. Experimental physics and chemistry is a broad area. The basic and applied research necessary to understand and catalogue the phenomena which dominate in the absence of containers, sedimentation, and gravity-driven convection, require the near-zero-gravity environment available in space. Based on Skylab results, it is almost certain that new experimental phenomena and new areas for scientific investigation will be found from these experiments.

The spectrum of technical areas that may be considered for experimentation in the weightlessness of space include catalytic chemistry, electrochemical deposition, electrolysis, rate-sensitive reactions dominated by convective mass transport, critical point phenomena, measurement of certain phase diagrams, surface tension, thermophysical property measurements, formation of thin films with and without surfactants, fluid surface dynamics, non-gravity mechanisms and convections, capillarity, aerosol mechanisms, surface waves, gas jets, interfacial kinetics, cloud physics, foam formations and stability, liquid dispersion, bubble regimes, boiling phenomena, combustion, and vapor deposition. This spectrum of opportunities must be reviewed in detail to select for early implementation those opportunities of most scientific and industrial importance.

Significant increase in knowledge of critical point phenomena, improved combustion safety standards, and understanding of lean combustion in internal combustion engines may be expected by 1985. We should also understand and have limiting convection phenomena catalogued. Long outstanding classical problems which also might be solved in this time period include: equilibrium shapes and stability of rotating liquid masses, stability of fluid jets; stability of charged liquid drops;

understanding of drop fusion and fission; behavior of strongly oscillating liquid drops; effect of gravity on the critical point of fluids; behavior of fluids (particularly superfluids) at consolute points; the behavior of a flame front in lean combustion; and understanding of the processes in free gas jet expansion.

As in other areas of basic research, physics and chemistry experiments in space can involve international cooperation and participation. A number of the experiments will align closely with and provide a foundation for, other activities such as those described under Objective 062, Materials Science.

Physics and chemistry laboratory experiments require human participation in the loop as an experiment adjuster, observer, and recorder of data. Several facilities are required, including (1) a fluid physics facility, (2) a fluid chemistry facility, (3) a molecular beam laboratory (to exploit the monoenergetic oxygen beam due to the Shuttle velocity through the residual atmosphere at orbital altitudes), and (4) a combustion facility. The technologies involved in these facilities will be extensions of Earth-based laboratory techniques into space. Physics and chemistry experiments will not generally require dedicated flights but will probably be part of a varied payload.

Objective 062 – Materials Science

The purpose of this objective is to advance materials science through research in a weightless environment. The capability and rate of advancement in many technical fields, such as metals, optics and electronics, is critically dependent upon materials. In most areas of materials science, the actual properties of materials are far below the theoretical limit. Widespread research in metallurgy, crystals, glasses, ceramics, alloys, and chemicals is done today in an effort to scientifically produce quantities of materials having actual properties closer to the theoretical limit. These small quantities of materials are the basis of development work for applications in many fields and serve as benchmarks for the economic production of applied new materials with superior properties.

Applied solid materials are often formed from a fluid phase. The transition often involves (1) concentration and thermal density gradients which result in unwanted convection effects in gravity, (2) melted materials that are contaminated by their containers in gravity, (3) unwanted settling in suspensions which occurs due to gravity, and (4) container-induced stresses at high temperature. It is expected that these limitations will be eliminated or minimized in the near-zero-gravity environment. Several Skylab experiments support this expectation, and demonstrate that larger and more homogeneous samples can be made in the weightlessness condition. Consequently, it is expected that experiments in space will lead to: (1) Establishment of material property limits to stimulate progress in ground-based techniques; (2) Production of materials with improved properties to serve as benchmarks for ground processing; and (3) New materials with unique properties. We note that the exploitation of this promising field requires a strong R&D activity in space.

Generally, three kinds of facilities are required to accomplish the goals of nearly all the suggested experiments: (1) a furnace facility, (2) a levitation facility, and (3) a general-purpose facility. Obviously, materials processed in space have to be returned. A strong flight program between now and 1985 appears necessary to develop the knowledge needed to enter into commercial production of materials in space and for application to Earth-based materials science and manufacturing.

Objective 063 – Commercial Inorganic Processing

The purpose of this objective is to determine the potential of commercial inorganic processing in a weightless environment. The feasibility of the commercial production in space of inorganic solid materials and device components that are cheaper and/or superior to ground-produced materials will depend upon the results of the previously discussed objective. As was indicated above, space offers the material processor freedom from: (1) gravitationally induced convection in fluid phases during the formation of solids, (2) container stress and contamination, (3) plastic deformation (sag) at high processing temperatures (which causes deterioration of properties), and (4) buoyancy separation of suspensions.

The potentially unique contributions that may result from these technical considerations make the concept of commercial processing in space attractive. This attractiveness is enhanced because of the existing pressures for higher performance materials in general and the expected trend of reducing costs for traffic to Earth orbit in the 1980s and 1990s.

The significance of inorganic material processing in space is broad because of the wide variety of potential commercial applications in which the subject materials are used. Semiconductors, magnetic detectors, opticals, superconductors, and piezoelectrics are a few of the materials being studied.

The economic benefits of materials processing in space hold promise, but are currently not amenable to definitive cost-benefit studies. Preliminary studies have identified many potential materials for which space processing might provide potential economic benefits. Examples include silicon ribbon and lithium niobate.

The manufacture of high-quality metals, crystals, glasses, and chemicals requires high-temperature furnaces of various capabilities, chemical reaction chambers, levitation systems, and controlled chamber atmospheres and pressures. Presently on Earth, each manufacturing plant is tailored to the subject material. Overcoming practical problems of weightlessness will result in new designs and require demonstration and pilot plant activity. The repetitive nature and slow time constants of most high-temperature and vapor processes require long periods in orbit. A permanent space station is an attractive orbital vehicle to accomplish much of this activity because it eliminates the requirement to re-orbit heavy support equipment and allows continuous operation with technical risk kept to a minimum. Much technological development for levitating free-floating specimens of high-temperature melts is required prior to the operational phase.

We foresee the period 1980 to 1985 for research and development in low gravity (Objective 062) as a precursor step for building the technology and for verifying principles to launch an aggressive program of commercial materials processing in space.

Objective 064 – Biological Materials Research and Applications

The purpose of Objective 064 is to produce or isolate biological materials by processes which require weightlessness. Some of the unique effects of weightlessness on the behavior of inorganic materials may apply to biological materials as well. Some biological entities, including functionally important cell subtypes, cannot be satisfactorily isolated with current separation techniques. Electrophoresis, the separation of particles of different mass/charge ratios in an electric field, is a widely used research and clinical technique. However, electrophoretic separation of cells has not been very successful because of sedimentation and other gravity-induced effects. Very accurate separation in zero-gravity is theoretically achievable, and a number of applications are available for such a process. The separation of human lymphocytes into their functional subtypes would assist research into the characteristics of these cells; separation of human kidney cells may permit pure tissue culture of that fraction which produces the enzyme urokinase, a substance with a potentially important clinical application, dissolving blood clots in the body. Urokinase is now in very limited supply and very expensive. Its production from purified cell cultures could reduce the cost by an order of magnitude or more, and stimulate its use in clinical research.

Research with other cell types, including cancer cells and cell producers of erythropoetin and specific immunoglobulins, might also benefit from this procedure. Commercial applications may ultimately be found. For example, the separation of semen for sex control of livestock could result in increased meat production.

Since this field is in its infancy, its economic impact is not known. A research program is needed to evaluate carefully the behavior of such biological preparations in weightlessness, and their response to various manipulations. In some cases, large volumes of starting material may be needed. In general, biological and pharmaceutical processing in space will require different kinds of support devices than the rest of materials processing in space. The application of rather simple techniques to biologicals and pharmaceuticals becomes extremely complicated because of the sensitivity of the materials to contamination, temperature, pH, salinity, and concentration. This is especially true in electrophoresis.

Objective 065 – Effects of Gravity on Terrestrial Life

This objective will attempt to determine the effects of gravity on the evolution and forms of terrestrial life. Gravity has been a ubiquitous and fundamental influence on the evolution of terrestrial life forms. Primitive life forms such as bacteria are themselves essentially insensitive to gravity orientation; but as organisms increase in complexity, special adaptations to gravity appear in the cardiovascular system, the bones and muscles, and in special sense organs such as the vestibular system, which is essentially an acceleration sensor. Higher plants also show specialized adaptations to gravity; in biosatellite flights in Earth orbit, root and shoot growth patterns differed from normal. Weightlessness causes profound changes in these gravity-adapted body systems in human beings, as the Skylab results have shown. But the preliminary flight evidence to date has not shown change at the cellular or subcellular levels, with the possible exception of increased growth of an E. Coli phage virus in some Soviet flights. Theoretically, units as small as one micron might be affected, and altered growth patterns can be observed on fungi on the clinostat.

The effects of weightlessness, and therefore of gravity, need to be studied in gravity-sensitive life forms of various degrees of evolutionary complexity, at both the cellular and system levels, and for several sequential generations in order to answer the questions that preliminary results have raised: (1) How are growth, development, maturation, reproduction, and aging affected? (2) At what level of evolutionary sophistication do significant gravity adaptations occur? What is their effect on the organism's response to weightlessness? (3) If acclimatization to weightlessness occurs, does it impair the organism's ability to re-acclimatize to normal gravity?

A variety of gravity-sensitive life forms maintained long enough to allow zero-gravity adaptive patterns to develop and stabilize could be of high scientific significance.

Preliminary work can be done on Shuttle/Spacelabs. The need for long flight durations and for experiments tended by human beings requires a station independent of the Shuttle.

The species chosen for examination in the space station will be those in which the imposition of weightlessness will help answer critical questions about gravity sensitive systems. It is important to avoid flying a wide variety of species in the hope that serendipity will reveal some interesting new problems. We now know enough about the effects of gravity at all levels of complexity in many organisms to be able to make judicious selections of the most promising experiments in selected species, for example, fungal growth, geotropism in higher plants, insect flight, the neurophysiology of adaption to weightlessness and motion sickness in selected species, the loss of bone structure, cardiovascular and fluid balance changes, and changes in hormonal systems. It will be important also to compare the results with those of similar experiments on the clinostat on the ground. It has been claimed that many of the changes of weightlessness, particularly those with time constants of more than a minute or so, can be reproduced in the laboratory by the clinostat. This must be examined in detail.

Mission requirements dictate the use of a dedicated life sciences module for the space station so that experiments of weeks or months can be carried out. It should be possible to carry out reasonably sophisticated biological experiments in the module, and the design of the facility must meet this requirement.

Objective 066 – Living and Working in Space

We do not yet know whether human beings can live in full health and work effectively for years in space. This question must be answered before future long-duration human endeavors in space (such as those discussed in Chapter 7) are undertaken. We need to know in particular: what are the physiological and medical consequences of long-duration weightlessness, whether problems with any of the body systems can easily be prevented or countered, or whether major protective measures such as artificial gravity may be required; what are the safe human tolerance limits to ionizing radiation from the Sun, the galaxy and space nuclear power systems; what are the psychological effects and problems of prolonged stays in space for small and large groups of men and women; and how well can life-support systems be designed for extended operation in space.

Some of the important physiological effects of weightlessness, clearly demonstrated in the Skylab medical experiments program, are as follows: (1) There is a steady loss of calcium and phosphorus from the bones. There is no way of predicting whether this will continue to the point where the danger of fractures become unacceptable or whether it will level out at an acceptable figure. (2) In a fair percentage of flights to date, both cosmonauts and astronauts have developed space motion sickness, sometimes mild and sometimes severe. The mechanism is not fully understood, and the problem will be the subject of intensive research during the Shuttle/Spacelab era. The symptoms always disappear after a few days, so for long-duration missions of the future the problem is less severe than for missions of a few hours or days. (3) There is a significant redistribution of body fluids, probably due to the hydrostatic changes induced by weightlessness. (4) Red cell production is diminished, but then seems to recover. (5) There is an increased tendency to faint in the standing position after return to normal gravity, due to changes in the cardiovascular system. (6) There are some poorly understood electrolyte and hormone changes. In Skylab, measurements of physical task performance showed a progressive improvement in capability in all astronauts as they become familiar with the weightless environment. Maximum exercise capacity was normal in Skylab, testifying to the integrity of cardiovascular and respiratory functions in space (always provided adequate physical exercise is taken).

The most important change, from the point of view of exposing people to weightlessness for many years, is the loss of structural components of the bones. The question of whether this loss will stabilize can only be answered by exposures of human subjects to weightlessness for many months in a space station. If bone strength continues to decrease, then remedial measures must be examined. In the last analysis, artificial gravity would almost certainly solve the problem. However, artificial gravity produces physiological problems of its own, and these must be carefully examined. As the duration of exposure to the space environment increases, most of the human problems become accentuated. Radiation dosage becomes more important; the effects of personal interaction, group dynamics and behavior in general increase; microbiological and immunological problems could become significant; and the need for highly reliable systems for oxygen replenishment and water recovery, carbon dioxide and trace contaminant removal, and waste management increases.

All the changes described above must be understood in more detail. Many questions will be answered in the Shuttle/Spacelab era, but many will have to await a permanent space station, since many months or even years of exposure of a large group of subjects will be required to obtain satisfactory answers. Given an intensive effort over the 1980 to 2000 time period, it should be possible to answer the majority of the questions. Experimental work must be carried out in flight and on the ground, with human subjects and with animals.

We noted that the biomedical and biotechnological programs needed to solve these problems will have direct terrestrial benefits in enhancing our knowledge of physiology, medicine and behavior, in developing advanced biomedical technology, and in developing expertise in closed ecological systems.

A variety of ground research development programs is required in physiological and medical research facilities, and in specialized simulators reproducing in part the environment of space. Many of these must be integrated with subsequent intensive space flight experiments: first, in Shuttle delivered space laboratories, then in permanent space stations, and perhaps eventually on the Moon. In physiology, the emphasis will be on the skeletal and muscular systems, the cardiovascular system, and the central nervous system; in psychology, on the effects of long-duration confinement, group dynamics and crew structure and selection, and on human-machine interaction problems; in radiobiology, on the long-term effects of galactic particle radiation; in life support, on the long-term reliability of oxygen and water recovery; and of food regeneration systems in the case of the Moon. The design criteria for habitats in space are heavily dependent on the findings of these programs. It is critically important that a large number of men and women be exposed to weightlessness for months, and some for more than a year, as a prelude to extensive operations in space.

For this and similar objectives wherein people are experiencing long durations in space, a receiving facility is necessary to monitor their readaptability to Earth environment. The space facilities required are the same as for the Physiology and Disease research (Objective 067) in weightlessness.

Objective 067 – Physiology and Disease Processes

The purpose of this objective is to utilize weightlessness as a research tool to gain better understanding of physiology and disease in man. Weightlessness as a physiologic challenge to an organism can help us understand better its responses to other challenges. The absence of gravity causes profound alterations in certain body systems and functions, alterations similar to those seen in many disease states. The causes are not the same, but the mechanisms by which they are effected and the adaptive responses of the body may be substantially the same. This suggests two potentially fruitful lines of research: (1) determine the mechanisms of the observed zero-gravity changes in the absence of underlying pathology (e.g., bone demineralization, loss of red cells), (2) observe the zero-gravity time course of selected diseases in human or animal subjects. The diseases selected would be in body systems known to be sensitive to gravity, such as the cardiovascular, musculoskeletal and vestibular systems. The hoped-for results are a better understanding of the pathways whereby disease alters structure and function, and development of new ways to diagnose and treat illnesses on Earth. By-products of this research will be more accurate medical standards for the selection of space travelers, and ways to diagnose and treat illness during space flight.

This program has considerable scientific significance. The effort requires a long duration facility in space. The annual cost of medical research in the U.S. approximates 4 billion dollars; a small fraction of this amount would be well spent in utilizing weightlessness as a research tool to gain a better understanding of human physiology and disease by pursuing this objective.

Two flights per year of up to 30 days are required during the early 1980s which may be shared with the activities to determine the effects of gravity on life, and of living and working in space (Objectives 065 and 066). Medical and physiological research equipment is required. Core equipment consists of basic facilities which are flown on every mission and include refrigerators, freezers, incubators, sterile water system, cleaning and waste disposal equipment, microscopes, cameras, and certain common data equipment such as pen recorders, signal conditioners, and perhaps a small computer. Additional equipment will comprise items needed frequently but not always and which can be designed to serve most experimenters. Candidates include a mass spectrometer, cardiography equipment, radioisotope handling facility, and perhaps an animal centrifuge.

The output of the medical program utilizing the Shuttle/Spacelab system will be enhanced by the adequate payload capability and the opportunity to fly frequently and use larger numbers of subjects, including animals. But it will be severely limited by the relatively short durations possible. Principal looked-for results from Spacelab tests include:

- Further refinement and quantitation of changes observed to date
- Discovery of some mechanisms of change, including vestibular and red cell mass changes, largely through the study of instrumented animals
- "Snapshots" of the immediate responses to zero-gravity of a variety of gravity-sensitive life forms
- Sufficient experience with animal maintenance to permit design of efficient holding facilities for future programs

- Flight experience with a much wider cross-section of human crews, including some in less than perfect health

Most of the really challenging questions will not be answered until durations of six to twelve months have been achieved.

A space station is required in the post-1985 time period to provide long duration (6 to 12 months) to achieve the desired 30 to 60 human years of exposure. Medical and physiological research facilities as well as animal handling facilities will be required.

Summary Observations on Theme 06

For the purposes of this study, we assumed that the objectives of this theme would be implemented in a combination of Spacelabs initially, and permanent space stations eventually. More specifically, we assumed that Basic Physics and Chemistry, Materials Science, and Biological Materials Research (Objectives 061, 062, and 064) would share a Spacelab. This Spacelab would be flown approximately four times a year for periods between seven and 30 days in the 1981 to 1987 time period. Starting in 1987 and continuing until the end of the century, these activities could occupy one module of a permanent space station. The activities in Effects of Gravity, Living in Space, and Physiology and Disease (Objectives 065, 066, and 067) would also share a Spacelab and a space station in a similar fashion, the only difference being that the frequency of flight of the Spacelab would be twice a year rather than four times a year during the 1981 to 1987 time period. The number of Spacelab structures required to support all Spacelab missions is not specifically addressed in this study. A more detailed study will be required to determine to what extent the instruments and equipments necessary to support related objectives can be removed between missions to allow a particular Spacelab structure to support other unrelated objectives. In some cases, the Spacelab may actually be part lab and part pallet. This degree of design definition is also beyond the scope of the present effort. We assumed that Commercial Processing (Objective 063) in space would not be a reality before the late 1980s. Consequently, for planning or illustrative purposes, a space station module is projected for use in achieving this objective.

Our general observations on this theme are summarized as follows:

- Zero-g environment offers opportunity for a wide spectrum of physical-chemical phenomena research. The many opportunities should be carefully evaluated to optimize planned implementation.
- Skylab tests related to material processes are promising and future activities should provide:
  - Establishment of material property limits to stimulate progress in ground-based techniques
  - Production of materials with improved properties serve as benchmarks for ground processing

  - New materials with unique properties
  - Potential for commercial processing in space
- The exploitation of the zero-g technique will be severely limited until availability of Spacelab.
- Assuming success in developing zero-g processing techniques and reducing transportation costs to space, increasing costs of processing on Earth due to energy shortages will accentuate the interest in space processing.
- Zero-gravity environment offers opportunity to study effects of weightlessness on all levels of life forms at both the cellular and systems level to answer questions such as:
  - How are growth, development, maturation and reproduction affected?
  - At what levels of sophistication do gravity adaptations occur, and by what mechanism?
  - Does readaptation to weightlessness occur, is it tolerated by the organism, and does it result in loss of ability to survive in gravity?
  - Are some gravity adaptations genetic and unaltered by exposure to weightlessness?
- Extended and long-term space activities will require answers to:
  - What are the physiological and medical consequences of long duration weightlessness?
  - What problems with any of the body systems can easily be prevented or countered?
  - What major protective measures such as artificial gravity may be required?
  - What are the safe human tolerance limits to ionizing radiation from the Sun, the galaxy and nuclear power systems?
  - What are the psychological effects of prolonged stays in space for small and large groups of men and women?
  - How well can life-support systems be designed for extended operation in space?
- Experience to date indicates that the study of the zero-gravity time course of disease in gravity sensitive systems should aid in the understanding of the physiology of the disease.

THEME 07: Earth Science

The first five Earth-oriented themes are heavily oriented toward applying space activities to meet a variety of human needs. This application of space activities in many cases is made possible by earlier scientific investigation. In order to provide a continuing scientific base for future applications and to directly support a number of proposed objectives in the first five themes, an Earth Science theme is considered an important part of any Earth-oriented space program.

In this theme we are interested in determining the causes of the Earth's magnetic field; what the geomagnetic field can tell us of the Earth's interior; determining the nature and cause of crustal dynamics; developing an understanding of the ocean interior and dynamics; developing an understanding of the dynamics and energies of the lower atmosphere; describing the structure, chemistry, and dynamics of the stratosphere and mesosphere; and determining how the ionosphere is coupled with the magnetosphere.

Objective 071 – Earth's Magnetic Field

The purpose of Objective 071 is to determine the causes of the Earth's magnetic field and what the geomagnetic field can tell us of the Earth's interior. Study of the Earth's magnetic field is important because understanding the composition and dynamics of the Earth's interior is fundamental to understanding the planet we live on, and because fluctuations in the geomagnetic field may affect the biological environment on the Earth's surface. Magnetometer surveys of the Earth, to nanotesla accuracy, are a necessary ingredient to achieve this understanding.

The geomagnetic field is one of the few observables containing information about the interior of the Earth. It is thought to be caused by dynamic action in the liquid outer core of the Earth, and the field contains components from the source in the core and from magnetized material in the upper lithosphere. Variation of the main field may reflect changes not only in the source process, but also modulation of changes in the conducting mantle. Ambient variations caused by magnetospheric source also cause shallower currents which are modified by the lithosphere. The total spectrum of the internal field and the Earth's response to transient variations may give clues to global tectonic structure.

The geomagnetic field shields the Earth's biosphere from potentially harmful solar radiations, so fluctuations in the field strength, or conceivably field reversals, are of immediate practical importance.

A three-satellite system, operating at 1000 km altitude would re-survey the Earth's magnetic field every five to seven years. The vector field at the Earth's surface varies on the order of 500 nanoteslas (gammas) over a 10-year period. Magnetometer accuracy must be consistent with these changes. To correlate magnetic field measurements and Earth anomalies, a higher-resolution survey of the Earth is required than previously available.

Objective 072 – Crustal Dynamics

This objective will attempt to determine the nature and cause of crustal dynamics. Crustal dynamics, which may be the most important element in Earth science today, is central to the understanding of the origin and evolution of the Earth and the other planets. Dynamic processes formed the continents and the ocean basins, mountains and islands; they are manifested in the earthquakes, volcanoes, and tsunamis which shape the face of the Earth; and the dynamic processes within the Earth form our natural resources of mineral and hydrocarbons. To control and make use of our environment, we must understand geodynamics.

During the last decade, a revolution has occurred in Earth sciences. Its impact is comparable to what happened in physics around the close of the 19th Century. The unifying concept is plate tectonics, which modeled Earth structure and geodynamics in terms of a small number of rigid plates covering the Earth's surface, and moving relative to one another. The plates diverge at ocean ridges, where new material wells up from depth to fill the gap; they converge along seismically-active continental margins and island arcs where one or both plates are underthrust and consumed back into the mantle.

Very active international research projects are now seeking to refine the basic model of plate tectonics and to understand the dynamics of the plates. One of the most important problems is the driving mechanisms. Current hypotheses favor a model in which the plates are dragged along by convection currents in the Earth's mantle, although there are arguments in favor of gravitational sinking of the cold dense underthrust slabs, which would pull the plates along behind them.

Vertical movements, which are large in extent and of great importance geologically and economically (petroleum deposits are controlled by such movements), are not explained by present models. The locations of several types of mineral deposits, for example, copper, chromium, and manganese, are now understood in terms of their relation to ancient mid-ocean ridges and other plate-tectonic features. Most major earthquakes occur where the plates are colliding and underthrusting; there now appears to be a reasonable prospect of being able eventually to predict and to influence earthquakes and perhaps volcanic eruptions. A long-range effort to monitor crustal plate motion should be undertaken to support further verification of the plate tectonic theory and to support the development of a phenomenological model.

The nature and causes of crustal dynamics can be pursued with several types of missions. (1) A long-range effort to monitor crustal plate motions would use extraterrestrial reference points. Possible methods include long-baseline microwave interferometry using extra-galactic radio sources, laser ranging on the retro-reflectors emplaced on the Moon during the 1960s, and laser ranging on artificial satellites. The importance of these measurements is such that more than one method should be developed, so that cross-checking is possible. (2) Knowledge of the density distribution within the earth is an essential tool in interpreting geophysical data relevant to geodynamics. Geodetic satellites would be continued; these can also yield (through sea-level altimetry) crucial data on the general circulation of the oceans. (3) A unique contribution can be made by using communications satellites to relay geophysical data from remote monitoring sites, both to allow instrumentation of inaccessible areas and to help in early warning of tsunamis and of volcanic eruptions. (4) Major benefits can be expected from a long-term commitment to support theoretical studies and model synthesis work by earth scientists.

Objective 073 – Ocean Interior and Dynamics

Oceans are major reservoirs of heat and their dynamics, therefore, play a significant role in determining global as well as regional climate. Over half of the solar radiation, along with the surface wind stress, is the ultimate energy source for a variety of physical processes in the ocean. The absorption of solar radiation is primarily responsible for the existence of a warm surface mixed layer of the order of 100 meters deep found in most of the world's oceans. This warm surface layer represents a large reservoir of heat, and acts as a significant thermodynamic constraint on atmospheric circulation.

The exchange of the ocean's heat with the atmosphere occurs over a wide range of time scales, and largely determines the relative importance of other physical processes in the ocean for climatic change. Some of this heat is used for surface evaporation and is eventually deposited in the atmosphere as latent heat during cloud formation; some is stored in the surface layer; and, some is moved downward into deeper water by various dynamical and thermodynamical processes. The fluxes of latent heat into the atmosphere are comparable in magnitude to the energy deposited via radiation. Therefore, the dynamics of the ocean's surface layer and its thermal state must be taken into account in even the simplest of climate models.

It is becoming apparent that the most energetic motion scale in the oceans is that of the mesoscale eddy, whose period is of the order of a few months and whose horizontal wavelength is of the order of several hundred kilometers. In a general sense, these slowly-evolving eddies are the counterpart of the larger-scale cyclones and anti-cyclones in the atmosphere. An understanding of the physical processes responsible for the origin and behavior of these eddies is essential for further insight into the dynamics of the global oceans, which should be coupled with similarly accurate and compatible atmospheric models.

Study of large-scale dynamics of the complete oceanic circulation, including "currents" and their associated horizontal and vertical transports of heat, momentum, and salt, is of particular importance for the understanding of global heat balance and questions related to long-term climatic changes, such as Ice Ages.

Global surveys of ocean characteristics would be required in support of the development of dynamically and energetically correct ocean models. A global observation program with long-term monitoring of accurate ocean surface temperature would be a key element of this objective. Finer horizontal resolution is required over the paths of the currents, regions of upwelling, etc. In addition, measurements of salinity, sea state, and monitoring of the extent of polar caps could be of great interest to both oceanographers and to the student of climatic change.

The measurements required for this objective can be obtained in meeting other objectives. It is important, however, that these data be used for increasing our fundamental scientific understanding of the Earth. This is true for all the objectives of Theme 7. Sea surface temperature would derive from the activities of Forecasting Water Availability, Large-scale Weather, and Global Marine Conditions (Objectives 012, 021, and 026). Continuous monitoring of surface temperature in the Gulf of Mexico and off the U.S. coasts can be afforded from the activity on Local Weather and Severe Storms (Objective 031). Salinity measurements can be provided from the Water Availability Activity (Objective 012). The extent of the polar ice caps can be monitored with the system used for Large Scale and Global Marine Weather Forecasting (Objectives 021 and 026). Surface topography can also be provided from the latter of those activities.

Objective 074 – Dynamics and Energetics of the Lower Atmosphere

The purpose of this objective is to develop an understanding of the dynamics and energies of the lower atmosphere. There are certain fundamental, unsolved questions in atmospheric sciences whose answers could influence our ability to understand phenomena ranging from tornadoes and turbulence to long-term climatic changes.

Major advances in atmospheric sciences during the last two decades have come about because of our ability to "model" the large-scale atmospheric phenomenon with high-speed computers and compare the "model" with actual observations over the entire globe. Broad features of atmospheric dynamics and energy balance are, therefore, understood in principle. A number of questions remain: What is a front? Can we formulate a theory of frontogenesis? What is the mechanism of tornado formation? Can we ever predict its path? Is turbulence the most efficient instability in the atmosphere? What is the nature of intertropical convergence zone and what is the importance of cumulus convection in tropical circulation? Do we possess enough observational definition to formulate an acceptable theory for hurricanes or typhoons? Can the problem of the long-term climate changes be quantified? What are the precise roles of solar variation, ocean dynamics, and atmospheric chemistry and cloudiness changes in determining the climate? A detailed effort to attack problems related to weather and climate, involving observations and analytical approaches with a process for interaction between the several groups involved, is embodied in this objective.

A three-pronged attack on this objective would be most productive. First, an intensive observational program at proper (not necessarily the highest) resolution; second, development of mathematical and physical techniques to model the phenomenon; and third, a feedback process between "modelers and observationalists" in order to define the optimum experiments in observation and modeling. A stimulus to this field, both in terms of ideas and competent physicists is already coming from the studies of the atmospheres of other planets. A well-designed program to observe the atmospheres of Mars, Venus, and Jupiter can provide many of the crucial tests for theories in atmospheric sciences.

All mission requirements for this objective can be met with the space systems described under Large Scale Weather, Climate, Stratospheric Changes and Effects, Global Marine Weather and Local Weather and Severe Storms (Objectives 021, 023, 024, 026, and 031, respectively). Special emphasis is required to:

- Develop mathematical and physical techniques to model phenomenon
- Conduct studies of atmospheres of other planets with tests for theories of atmospheric phenomenon

Objective 075 – Structure, Chemistry and Dynamics of the Stratosphere and Mesosphere

The stratosphere and mesosphere are probably the least understood parts of the atmosphere, and the stratosphere is becoming increasingly significant as we begin to recognize the perturbing effects human activities can have on the delicate chemistry of this region.

These regions, with altitudes between 15 and 100 km, are even less understood than the atmosphere above 100 km, where measurements by rockets and satellites combined with a concerted effort by aeronomists have considerably improved our knowledge during the last decade. As for the stratosphere, it is only now that high-altitude balloons and aircraft, along with sophisticated, remote sounding techniques from the Earth-orbiting spacecraft, are beginning to provide us with long awaited data on space and time variations in temperature and composition. Parallel to this, computer technology has developed to the stage that data on stratospheric parameters now being acquired can be fed into these models of the atmosphere. Stratospheric research is finally emerging as a major scientific discipline.

We are witnessing a major upturn of interest in the stratosphere because of the potential climatic impact of the supersonic transport and the freons from aerosols. As often happens in controversial cases, a large number of studies have been initiated to assess the impact of stratospheric aviation. A proper assessment of these impacts can only be achieved when we understand the functioning of the stratosphere from basic research studies.

A coordinated program for the studies of the stratosphere and mesosphere should have major emphasis in the following three categories: (1) A description of the natural stratosphere and mesosphere: structure, composition, dynamics, chemical and radiative processes involving measurements in the atmosphere and modeling in large capacity computers; (2) Development of new techniques and instrumentation for measuring stratospheric parameters relevant for the description, including not only instrument development such as super-sensitive mass spectrometers but also laboratory measurements of chemical reaction rates, etc.; (3) Identification of gaseous and particulate pollutants, their dynamics, lifetime and eventual impact on the structure of the atmosphere, involving long-term monitoring of the chemistry of the stratosphere and mesosphere.

The space measurements required to achieve this objective are generated in the activities on Stratospheric Changes and Effects (Objective 024). Measurements of ozone, aerosols, and CO_2 are required. Spacecraft ozone measurements are already being obtained and planned satellites will be devoted to: (1) measurements of the stratosphere and troposphere; (2) aerosol measurements in the mid- and equatorial latitudes; and, (3) measuring trace constituents and aerosols before 1985. Developmental emphasis would be to:

- Model natural stratosphere and mesosphere involving structure, composition, dynamics, and chemical and radiative processes
- Develop new techniques and instrumentation for measuring stratospheric parameters
- Conduct laboratory measurements of selected chemical reaction rates.

Objective 076 – Ionosphere-Magnetosphere Coupling

A clear understanding of the coupling mechanism between the magnetosphere and ionosphere will enhance our ability to know how the Sun "controls" the upper atmosphere of the Earth. It is important to define an objective for a continued experimental and analytical program to define the coupling between the ionosphere and the magnetosphere.

Both the electromagnetic radiation from the Sun and the solar wind change continuously because of the violent activity going on in the outer layers of the Sun. Changes in the solar wind flux impact the structure of the Earth's magnetosphere while the changes in the electromagnetic radiation, which are mainly in the ultraviolet and X-rays, impact the ionosphere. At the same time, the energetic particles of the magnetosphere can precipitate down to the ionosphere levels and below (auroras) while the ionized particles of the ionosphere could diffuse out to the magnetosphere. What really happens after a major burst of solar activity is uncertain. A number of intriguing questions remain unanswered: Under what circumstances and how far do charged particles precipitate down into the neutral atmosphere? What kinds of plasma instabilities are generated? What role does the atmospheric dynamics play in the transfer of energy and momentum between the magnetosphere and ionosphere? How are chemistry and temperature structure related in the ionosphere?

A combination of active experiments from the Shuttle, and atmospheric and electrodynamic instrumentation satellites is required to begin to answer questions implicit in this objective. Active experiments would be conducted where the upper atmosphere is intentionally perturbed in order to study its transient behavior.

Summary Observation on Theme 07

- Magnetometer surveys of increased resolution of the Earth are desirable to support studies of the composition and dynamics of the Earth's interior.
- Space-derived techniques should be used to monitor crustal plate motion to support further verification of the plate tectonic theory and the development of a phenomenological model.
- Global surveys of the ocean should be pursued in support of the development of dynamically and energetically correct ocean models.
- The ocean models should be coupled with appropriate atmospheric models to provide tools for the understanding and prediction of climate trends.
- A number of important questions concerning dynamics and energies of the lower atmosphere have been identified and should be pursued with a joint analytical and observational approach.
- Increased interaction between researchers concerned with planetary atmospheres and the Earth's atmosphere should be encouraged.
- A coordinated effort should be undertaken to improve our understanding of the stratosphere and mesosphere including the identification of gases and particulates which interact with these regions.
- To better understand solar effects on the upper atmosphere, an experimental/analytical effort should be continued to define the coupling between the ionosphere and the magnetosphere.

EXTRATERRESTRIAL ACTIVITIES

THEME DEVELOPMENT

Extraterrestrial space activities look outward beyond the Earth, addressing the human need to understand. They are therefore influenced by such trends mentioned in Chapter 4 as the accumulation of scientific and technical knowledge, the appreciation and use of theoretical knowledge, attitudes toward challenge, and strongly by the desire to understand the origins and future of our planet and ourselves in the Universe.

Extraterrestrial space activities that the Study Group considered range from the recordings of γ-ray bursts occurring somewhere in the Universe to the complete mapping of the surface of Mars; from the sophisticated analysis of the solar wind to the astronaut collecting geological data on the Moon; from the close-in passage of spacecraft through Jupiter's radiation belts to the mapping of the sky in X-rays; from the extensive investigations of the Sun to the search for deuterium on Venus. All of these activities have the same basic rationale. It is the modern scientific response to the challenge of the unknown: the three timeless riddles which all cultures of past and present have attempted to explain:

- How did the Universe begin and develop?
- How did life originate and evolve?
- What is our place and destiny in the Universe?

Scientific problems raised by these major questions are as diverse as the origins of man from inanimate material of the surface of the Earth, the motion of the continents, the spiralling hurricanes in the Caribbean, the formation of Earth and planets, the synthesis of elements in the centers of stars and the beginnings of the Universe itself. All are being pursued using the same basic laws of physics, chemistry and biology. All are related to the central question of the evolution of the cosmos.

Table 11

Steps in Cosmic Evolution

- ?
- BIG BANG
- MATTER
- GALAXIES AND STARS
- SUN AND PLANETS
- EARTH
- OCEANS AND ATMOSPHERE
- LIFE
- INTELLIGENCE
- ?

A concept of cosmic evolution, summarized in Table 11, and described in the following discussion, is receiving considerable attention today. This does not mean that it has been proven, nor that all scientists concerned with the broad range of studies involved in this theory agree with it – either in its detail or its overall structure. Yet it serves as a useful framework within which to define general themes of extraterrestrial investigation and to specify objectives to help guide the planning of specific programs in the Space Sciences.

The Study Group has not attempted to identify each of the many hypotheses held by eminent scientists that bear on the various objectives and questions discussed in the subsequent sections. We believe, however, that we have selected a representative group of such hypotheses, adequate for our analysis of the potentials of space flight.

The three basic questions about the origin and future of the Universe and of life have served as major stimuli to ground-based optical and radio astronomy, planetary science, exobiology, and related scientific disciplines. We do not wish to neglect their historic and substantial contributions, which form the basis of our present knowledge. On the contrary, the relatively new thrusts of space activities must form an essential and symbiotic counterpart to continuing Earth-based investigations. We do believe that these space activities will make a significant, and in some cases, decisive contribution to our general understanding of the cosmos.

A Concept of Cosmic Evolution

The Universe appears to have begun with a gigantic explosion 15 billion years ago, commonly referred to as the "Big Bang." The totality of matter of the Universe, probably in the form of the most fundamental particles in nature, namely electrons, protons and neutrons, was flung apart with tremendous speed. Within the first few minutes of the explosion, the protons and neutrons fused together to form hydrogen, deuterium, and some helium. As the Universe continued its expansion, the matter cooled and condensed into galaxies and within the galaxies into stars. In the interior of the stars, the temperature was raised again to millions of degrees, which allowed hydrogen to fuse in a series of reactions, forming helium first and then many of the remaining substances of the Universe. All of the other elements were formed when the more massive stars exploded just before they died.

Today, 15 billion years later, the Universe is still expanding. Many of the stars which formed at the beginning have since died, to end up either as infinitely compressed objects (black holes) or in spectacular explosions which spread the freshly cooked matter all over the galaxy. From this material, new stars formed and evolved. One of the 100 billion galaxies is our own Milky Way, which in itself contains 100 billion stars. One of these stars, the Sun, was born about 5 billion years ago. As the Sun formed from a cloud of gas and dust, some material was trapped in orbits around it and gave birth to the planets, including the Earth.

For millions of years, no living form existed on our planet; the atmosphere was probably filled with mixtures of carbon dioxide, nitrogen, ammonia and water vapor; flashes of lightning or solar ultraviolet radiation, or both, synthesized large amounts of amino acids, sugars and fatty acids and gradually these critical molecules accumulated in the Earth's oceans. Collisions occurred between them, now and then, linking small molecules into larger ones such as nucleotides. During the course of perhaps millions of years, the concentration of these molecules increased so much that the oceans became like a "soup." Eventually the living cell appeared and the threshold was crossed from the nonliving to the living state. It is now believed that the entire process could be a common event on planets throughout the Universe.

Slowly in the next three billion years, life on Earth evolved to reach a state of intelligence. An infinitely minor fraction of the matter of the Universe has now been converted to the organic material of the human brain. As a result, one part of the Universe can now reflect upon the whole process of evolution leading to existence of human thought. We wonder whether this process also is a frequent occurrence in the Universe.

This is an exciting concept and comes closer than ever before to achieving one of the very basic objectives of physics, namely to be able to organize all our present knowledge in a single deductive logical system. We do not know at the present time the extent to which various aspects of the "Big Bang" theory are in fact true. For example, although there may be billions of other planets in our galaxy, we do not yet have unambiguous evidence of even one planet outside of our solar system. Life may have originated on many of these planets, but we have evidence only for our own planet. Intelligent life may be widespread in the Universe, but we have not yet made contact with it. Many gaps, puzzles and uncertainties therefore remain. However these unifying concepts, in which the expansion of the Universe, the birth and death of galaxies and stars, formation of planets, the origins of life, and the ascent of human beings are all explained by the different features of the process of cosmic evolution, present an impressive challenge to astronomers, physicists, geologists and biologists. The major task in the next several decades is to test and evaluate this theory at every critical point. It is probable that, in doing so, entirely new concepts will evolve. A new physics or even a new biology may be required to explain the various aspects of the Universe and the existence of life elsewhere, all of which would be a major step forward and a significant contribution to modern science.

Space activities can play a vital role in the next few decades in firming up our understanding of cosmic evolution. One reason is that the "window" through which we have been peering at the heavens throughout our history is essentially a "dark glass." Our atmosphere is opaque to some of the radiation emitted by the planets, stars, and galaxies. Even in the visible part of the spectrum, the perpetual motion of the atmosphere "blurs" the images and puts a practical limitation on the size of Earth-based telescopes. With space telescopes of moderate aperture and focal length, we will be able to see much farther. This capability to detect and measure very faint stars both in our own and in neighboring galaxies will be enormously important.

Confinement to Earth is the other major factor. Until the 1960s we could only look at things in space but not touch them. Today, however, we have the extraordinary capability of actually visiting the Moon and the planets and even bringing back pieces of those heavenly bodies which can be analyzed in depth to ascertain their structure, age, and history of evolution.

It must be stressed that our emphasis in analyzing the extraterrestrial themes – just as in the Earth-oriented themes – is on the opportunities for spaceflight. We have made no attempt to catalogue the numerous methods by which the various objectives can be approached by ground-based systems. We have sought to emphasize those opportunities in which spaceflight seems to offer unique advantages. In almost all cases, these advantages will be fully realized only if there is close coordination between space-based and ground-based observation programs. We have not, however, attempted any detailed trade-off studies between space and ground systems.

Over the last one or two decades, our ability to carry out space-based observations has grown remarkably. It is very likely that this growth will continue over the remainder of the century. Techniques of ground-based observation are undergoing a similarly rapid development. These facts complicate any attempt to trade off one approach against the other, certainly when we are attempting to look some 25 years into the future. It is important to note that over the same last two decades, our concepts of cosmology have undergone a similar revolution. Now, perhaps by coincidence, but more likely because of the historical correlation between the development of technique and the development of theory, we are in a position to identify a number of extremely intriguing questions, critical tests, and even diagnostic measurements for various aspects of the cosmic evolution theory. Some of these questions are: If this concept of origin is correct, then where and when did the Big Bang take place? What happened during the explosion? Did all galaxies form at the beginning or do they condense, evolve, and die as the stars do? If the Big Bang theory is not correct, can we discover evidence to support an alternative explanation? What are quasars? Is there enough mass in the Universe to stop its expansion? What is the nature of gravity? Do black holes really exist? How is the observed energy in quasars being generated? Are physical laws not universal? Do other stars have planetary systems? What processes occurred during the formation of the solar system? What drives solar activity? How does it affect our climate? What is the future of the Earth and Sun? What happened on Earth and on the Moon during the first billion years? How did life arise on the Earth? Does life exist elsewhere? Does intelligent life exist elsewhere? Can we communicate with this life?

These are broad questions of exceptional scientific interest. A program response to these questions could become a major component of space activities in the next several decades.

The Importance of Extraterrestrial Activities to the Quality of Life on Earth

The quality of life on Earth is tied closely to the conditions on the surface of the Earth and in the atmosphere. Human beings have reached their present state of evolution through intricate interaction with their environments. The ancient atmosphere and oceans molded our metabolism, but then the presence of life changed the surface and the atmosphere. Life and the planet evolved hand-in-hand with time scales of mutual adjustments of the order of millions of years. Today a delicate balance exists among the various parameters of the ecological system to provide a globally average temperature of 15°C (60°F); air containing "right" proportions of oxygen, nitrogen, carbon dioxide, and water vapor; a protective ozone layer blocking the lethal solar ultraviolet radiation from penetrating down to the surface; and the oceans "buffering" the entire ecological system with a time scale in keeping with the human needs.

However today, for the first time in history, human beings are close to dominating nature. In the process they are also altering the delicate balance of the natural system. In the last century, the amount of CO_2 in the atmosphere has increased by at least 20% (cf. Chapter 4). The dust content of the atmosphere over extended regions of land has gone up by a factor of at least five. The chemistry of many rivers and oceans is different from what it was only a few decades ago. How are these changes affecting the global climate? Has the change in the chemistry of the atmosphere already changed the solar radiation reaching the surface? If the amount of atmospheric pollution keeps increasing at the present rate, for the next 25 years, will we trigger an ice age or initiate the melting of the polar ice?

Considerable effort is required to answer these questions. They involve complex interactions among a number of parameters; solar input, which is dominant; radiative and convective transfer; chemical exchange between the atmosphere, crust, and the ocean; the Earth's rotation; and the state of cloudiness. Currently we are unable to cope with this problem, not necessarily because we lack data or computing capability, but because we lack fundamental insight into the precise role of each of the above parameters in determining the climate.

A major advance in our thinking could come from a close examination of Mars, Venus and Jupiter where the atmospheres are different, both in chemistry and size; the rotation rates range from 246 days on Venus to 10 hours on Jupiter; and cloud coverage varies from 100% on Venus to close to 0% on Mars.

It is by studying the Earth together with these other planets that we will begin to isolate the effects of various parameters which determine the ecological balance of a planet. But the dominant factor in determining the climate is, of course, the Sun. Its energy input to the surface of the Earth is assumed to be constant over the time scale of decades.

One of the major accomplishments of space programs during the last decades was to demonstrate the extreme variability of the Sun's ultraviolet. The energy deposited in the upper atmosphere of the Earth at certain wavelengths in a matter of days has been recorded. Does this energy propagate downwards and perturb our weather and climate? This is a question which is now being asked with more and more seriousness as we try to unfold the basic mechanism which drives the atmosphere. Precise monitoring of the solar radiation, at all wavelengths, is the obvious first input to this problem and can only be accomplished from space. The mechanism by which the upper atmosphere is "coupled" to the lower atmosphere is the other problem which can probably be clarified by observation of the Earth from space.

A study of the Sun, which provides the basic energy input to the surface of the Earth, and a study of our neighboring planets along with that of the Earth itself, are therefore essential elements for the understanding of our ecological system. Only when we have achieved this understanding will we be able to justly claim that we have begun to dominate nature and are ready judiciously to modify the system for the benefit of humanity.

In natural evolution, the future of humanity is linked to the future of the Earth, which in turn depends on the future of the Sun. On a large time scale, modern astronomy tells us that in about five billion years the Sun will get 10 thousands times brighter, oceans and even solid crust will evaporate, and all life will almost certainly disappear. On a shorter time scale, of the order of thousands of years, a drastic change in the chemistry of our atmosphere could lead to an entirely different temperature regime on the surface of the Earth.

At this point, it is important to remind ourselves of Venus: our closest neighbor and a planet of the same size and mass as the Earth, yet it has a surface temperature of about 1000°F. This is not because it is closer to the sun and therefore should be hotter, but because its atmosphere is mainly composed of CO_2 and is completely cloud covered, which causes Venus to absorb less solar energy than the Earth, but traps what energy it does absorb.

A modest change in the composition of the atmosphere could have a profound effect on the entire ecological system of Earth. What will be the impact on life is of course impossible to predict, yet it is clear that we are highly vulnerable to changes in our environment.

We also live in a period when, for the first time in history, humans have acquired the capability of destroying this entire civilization and therefore disassociating the future of the species from the future of the Earth. However, this is also the time when we see the beginning of the capability of leaving the planet Earth and starting new habitats elsewhere. Some believe that a small fraction of people from Earth, the vanguards of the evolutionary advance, will do that anyway, just as 300 million years ago a small fraction of fish emerged from the oceans to become the first animals that breathed air and walked on the land.

Whether and when we will leave the Earth as a natural evolutionary process driven by pressures and basic needs, or establish habitats elsewhere in the solar system because of our drive for exploration and knowledge, can only be speculated upon at this time. We do not know our destiny, but we do know, as we grapple with major problems on Earth, that space technology can both help solve these immediate problems and can also tell us how humanity fits into the evolution of the Earth and of the Universe.

Extraterrestrial Themes

Through space activities and technology we have the means of answering many of the timeless questions. We regard a comprehensive long-range plan to study the Earth, the planets, and the Universe as an essential part of the U.S. program in space. As a consequence, five themes seem most applicable for extraterrestrial space activities for the next 25 years. They embrace, partly in sequence, the key questions of cosmic evolution. They are:

Theme 08: The Nature of the Universe
Theme 09: The Origins and Fate of Matter
Theme 10: The Life Cycle of Sun and Stars
Theme 11: The Evolution of the Solar System
Theme 12: The Origins and Future of Life.

Following are brief discussions of the objectives we included within these themes. Appendix B provides information on typical systems to pursue the objectives.

THEME 08: The Nature of The Universe

The most significant current questions regarding the nature of the Universe relate to what happened during the Big Bang, how and when the galaxies were formed, are the quasars really the exploding nuclei of galaxies, is there enough mass in the Universe to eventually stop its current expansion, and whether the laws of gravity remain valid in the newly discovered regions of the Universe where the density may be as high as 1 billion ton/cm^3?

Objective 081 – How Did the Universe Begin?

A decade ago, many astronomers believed that the Universe had no beginnings. They believed that it would remain forever as we observe it today with new matter being created to maintain the mean density constant as the Universe expanded. A few years ago, astronomers discovered a diffuse background of radiation in the infrared which apparently reaches the Earth from beyond the local group of galaxies. This is exactly what we should observe if the Universe started with a giant explosion some 15 to 20 billion years ago. Immediately after the explosion, the radiation would be highly energetic and therefore of very short wavelength. However, with an expanding Universe, the wavelength would increase, and now would lie in the infrared and radio region exactly as if it were coming from a gas just below 3°K. If this "three-degree background" represents radiation from the primordial explosion, we might be able to measure our velocity with respect to it and hence verify the thesis of an original "fireball."

While nuclear reactions in stars can transform hydrogen into other elements, we have difficulty in explaining the production of hydrogen or its heavier isotope, deuterium, except in the initial explosion. Thus, the amount of deuterium we observe today in the Universe could also be a measure of the conditions during the original Big Bang.

In an effort to understand where and when the Big Bang took place, we should be able to measure the velocity of the Sun with respect to the center of the Universe with either a microwave (submillimeter) receiver or an infrared detector with good spectral resolution (about 10^{-3}) on a small (20-cm) telescope cooled to temperatures near that of liquid helium. The same instrumentation can measure the irregularities in the background which may indicate the density fluctuations from which galaxies are formed. If the fluctuations are small, a telescope nearer 1 meter in diameter may be necessary. These instruments can make some measurements from balloons, but a spacecraft above the atmosphere may be necessary to achieve the necessary accuracy.

To investigate the conditions during the Big Bang, a precise measure of deuterium is required, which can be accomplished with high-resolution spectrometers. For the interstellar matter and stars near the Sun, a telescope of 45-cm aperture will suffice. For determination of the deuterium content of distant stars and distant regions in our galaxy and for determination of the deuterium content in other galaxies, an aperture of close to 2.5 meters is required. Some information can be obtained from ground-based microwave receivers on radio telescopes and possibly from infrared spectrometers on large, ambient temperature telescopes.

In summary, two major questions pertinent to this objective are:

- What is the spectrum and isotropy of the infrared background?
- What is the deuterium content in various regions of the Universe?

Objective 082 – How Do Galaxies Form and Evolve?

The question of how galaxies form and evolve related to one of the basic assumptions in cosmology: namely, all galaxies were formed early in the life of the Universe. Observations from space can now either help validate this assumption or tell us whether galaxies are still forming. Either way, it will be an important advance in cosmology.

A second important problem in galactic physics is the shape of the galaxies. They may be irregular, globular, or spirals. The shape can be an indicator of the original angular momentum of the material from which the galaxies were formed, but does the shape evolve? If so, why and how? A detailed description of the evolution of the galactic shape is therefore of great interest.

A third question is related to the formation of elements heavier than hydrogen and helium which we believe are formed in the interior of the stars. Why then do we see the heavy elements in the oldest of the stars? Was there a tremendous burst of star formation immediately after the galaxies formed? Can we really deduce the ages of the stars by looking at the abundances of the heavy elements in their atmospheres?

The question related to the evolution of galaxies requires (1) infrared and microwave surveys of the sky which can tell us whether density variations did exist in the early Universe, and (2) a large telescope in space which can look far out in space and provide information on the density of galaxies at various periods in the past. The telescope can also search for changes in shapes and sizes of galaxies of different ages, while ultraviolet and infrared spectra of different stars can unravel the story of the formation of elements heavier than helium.

In summary, questions pertinent to this objective include:

- Can we detect early inhomogeneities?
- What is the effect of angular momentum of galaxies on star formation?
- Can we observe evolutionary effects in galaxies?
- Where did elements heavier than helium form?

Objective 083 – What are Quasars?

Quasars (quasi-stellar radio sources) are a major puzzle in astrophysics. We do not know whether they are nuclei of galaxies or an altogether new kind of massive objective. Are they located at the observable edge of the Universe or somewhere closer?

Quasars are sources of extremely strong radio emissions. If they are as distant as they seem to be, the total energy content of one of these objects is of the order of 10^{60} ergs, which equals the amount of energy which will be generated by consuming the entire mass of more than 500,000 suns. The optical sources associated with the quasars seem to have large red shifts and exceedingly small volumes. Some estimates are that the sources are the size of the solar system. If quasars are violent nuclei of distant galaxies, what generates the energy and how is it converted into radio waves? Why do we see galaxies with different levels of activities ranging from the Milky Way, with very modest activity in its nucleus, through the Seyfert galaxies where highly ionized gases are abundant, and the radio galaxies, to the quasars? In addition, there is a more basic question: are the observed red shifts reliable for measuring the distances to remote galaxies? Are they a reliable gauge of the distances to quasars?

A coordinated attack on the problem of quasars in particular, and that of the activity in the nucleus of a galaxy in general, will involve observations of the active galaxies in the whole range of the electromagnetic spectrum, using large-area gamma-ray telescopes, X-ray detectors, moderate size UV telescopes, infrared and radio interferometers. Most of these measurements will have to be made from Earth orbit or beyond, although ground-based radio telescopes will constitute a major element of the program.

In attempting to answer the question "What are Quasars," the following additional questions must be investigated:

- What are the energy content and generation mechanisms in active galaxies?
- Can we locate and define the nature of the activity in galaxies?
- What is the duration of activity in galaxies?
- What are the distances of active galaxies and quasars?

Objective 084 – Will the Universe Expand Forever?

It appears well established that at the present time the Universe is expanding. Will it expand forever or is it closed? To the first order, the answer to this question depends on two parameters: the present rate of expansion, and the rate at which this expansion is slowing down. These parameters are expressed in terms of the Hubble constant, H_0, which relates the distance of a galaxy to its velocity and the deceleration parameter, q_0. The latter is directly proportional to the mass density of the Universe. Both constants can be determined from measuring the red shifts of the spectra of galaxies of known distances. In addition, the deceleration parameter can be deduced from the amount of matter in the Universe, if we can measure the latter.

Both types of observations present significant difficulties. To measure the constants from the galaxy motions, it is necessary to have good data for many galaxies at large distances from the Earth. Since these galaxies are faint and apparently small, it is very difficult to determine their distances accurately. Clusters of galaxies are common and presumably stable, but we cannot detect enough luminous mass in these clusters to account for their stability. Even a small amount of material between galaxies could greatly increase the mass of the Universe because of the tremendous volume involved, but we have never detected matter between galaxies outside of clusters. Another way in which to determine the mass of the Universe is to determine the density of matter shortly after the original explosion, the Big Bang. A measure of deuterium and helium in the oldest objects can provide useful information on this subject.

Searching for "missing mass" in the Universe will involve:

- Grazing incidence X-ray telescopes to look for "hot" inter-galactic matter
- A combination of wide-field visual and X-ray telescopes in Earth orbit and ground-based radio telescopes to search for matter at the edges of the galaxies
- Very high energy cosmic ray detector and X-ray and gamma-ray detectors to probe the properties of the intergalactic medium
- A large space telescope to describe the geometry of the Universe with better precision.

Pertinent questions believed to be relevant to this objective include:

- Can we detect intracluster, intergalactic matter?
- Can we observe matter in galactic halos?
- Can we define the geometry of the Universe?

Objective 085 – What Is the Nature of Gravity?

The physical processes in the Universe are dominated by the interplay between the nuclear and gravitational forces – the strongest and weakest forces in nature. The strength of gravitational interaction between two elementary particles is only 10^{-3} that of the electromagnetic forces. Yet in the case of very massive and compact astronomical objects like neutron stars, the gravitational effects become quite dominant. It is therefore quite remarkable that one theory of graviation, the general theory of relativity, has so far withstood scrutiny under extreme conditions ranging from the near vacuum of the interstellar medium to the very compact objects like pulsars. Now as we begin to stretch the extremities even further and study objects like black holes or the nucleus of the Universe which produced the Big Bang, new variations in the universal laws may be called for. However, any new theory or a modification of well-accepted theory will have to meet observational and theoretical criteria which are steadily becoming more rigorous.

Using space techniques to check the validity of universal laws will require a variety of measurements for:

- Determining whether the gravitational constant is really constant

- Carrying out diagnostic tests which would distinguish among the various theories of relativity
- Attempting to detect gravity waves
- Developing a long-term monitoring program for obtaining accurate values of planetary ephemerides, including observations from Earth-based radar.

THEME 09: The Origins and Fate of Matter

It is now believed that hydrogen, a portion of helium and their isotopes were created in the original Big Bang. The rest of the elements were formed inside galaxies, inside stars, and in stellar explosions. Thus, every atom in our bodies, including the oxygen that we breathe, the carbon and nitrogen in our tissues, the calcium in our bones, and iron in our blood, was formed through the fusion of smaller atoms either at the center of a star or during the explosion of a star.

We do not know enough about the life cycle of the stars and galaxies to permit us to deduce a coherent story of the origin and fate of matter. But we can identify four broad areas of investigation which are very relevant both to questions related to the origin of elements and to the ultimate state of the matter.

Objective 091 – What is the Nature of Stellar Explosions?

Stars spend 99% of their lives burning hydrogen. When they have turned the hydrogen in their core to helium, the core begins to contract since there is no longer nuclear burning to provide support against gravity. This contraction releases energy causing the outer layers of the star to cool and expand. The star is now a red giant. Eventually, however, the core contraction releases enough energy to ignite helium which then burns to carbon. Eventually the star forms a carbon core in a manner similar to the formation of the helium core from the burning of hydrogen. If the mass of the star is initially less than about 1.5 times the mass of the Sun, then no further evolution occurs and the star is compressed into a volume the size of the Earth and dies as a "white dwarf."

More massive stars, however, end their nuclear fuel-burning lives in giant explosions called supernovae. In addition, other types of stellar explosions are known to occur. All release cosmic rays, gamma rays, X-rays, and radio emission, as well as optical and infrared radiation. More importantly, perhaps, they are the primary means by which the elements which are created in stars are recycled back into the interstellar medium. The material which they eject is responsible for much of the radio emission which we observe and for significant heating of the interstellar medium. The shock waves from the explosions have a major influence on the dynamics of this medium as well. We need to learn the detailed processes which trigger stellar explosions, the speed with which they occur, the amount of material involved in various types of explosions, the frequency with which each type occurs, and the details of the interaction of the expanding gas from the explosion and the ambient gas and dust with which it collides as it expands. For this purpose we need:

- A program in high energy astrophysics which would utilize X-ray, gamma-ray, and cosmic-ray detectors in space.
- A ground-based radio and optical program which would be integrated with telescopes in the infrared and ultraviolet, coupled with a vigorous theoretical program to study the various aspects of stellar explosions.

To make determinations concerning the nature of stellar explosions the following questions must be considered:

- What triggers a supernova explosion?
- Are supernovae the main source of cosmic rays?
- What is the nature of supernovae remenants?
- What nuclear reactions occur during explosions?

Objective 092 – What is the Nature of Black Holes?

Of interest only to theoreticians a few years ago, black holes are one of the most intriguing phenomena in modern physics. They represent matter in its final state after a long evolutionary history. Here, massive stars, at least three times the mass of the Sun, would be compressed into volumes of radii less than a few kilometers. The gravity of these objects is so high that even light cannot escape from them, therefore the term Black Hole. Another superdense object is the neutron star, which is somewhat less dense and slightly bigger than the black holes. These have actually been detected in the sky as pulsars. Both these objects are sites of intense and violent physical processes leading to the generation of vast quantities of energy in the form of electromagnetic, corpuscular, and, presumably, gravitational radiations.

As mentioned, the existence of neutron stars is no longer in doubt because they are observable as radio, optical, X-ray, and gamma-ray pulsars. This is not the case for black holes. Although they may have been detected as a rapidly varying X-ray source, astronomers are not sure of this interpretation. The fundamental question thus remains: Are black holes observable, and if so how? There are other questions as well: Is there only one kind of black hole, or is there a variety of these objects? Are there white holes? What is the relationship between black holes and neutron stars and supernova explosions? Can black holes be formed without supernova explosions? How is observable radiation produced from a black hole? What is the detailed structure of space around a black hole? Are cosmic rays accelerated by neutron stars? What is the nature of black holes? In addition, to search for the detect gravitational waves and neutrino bursts would contribute considerably to this objective.

Detailed questions concerning the nature of black holes include:

- Do black holes really exist or are they only a mathematical anomaly?
- What is the distribution of black holes in the Universe?
- How much mass of the Universe is contained in the black holes?

Objective 093 – Where and How Were Elements Formed?

The origin of elements is intimately associated with the life cycle of a star and the dramatic events that take place during the death of massive stars. One theory is that hydrogen and helium, including their stable isotopes, were produced in galaxies, and with the exception of the light nuclei lithium, beryllium and boron, they are nucleosynthesized in stars.

While all stars may eventually contribute to the production of carbon, nitrogen, and oxygen, the heavier elements are probably made inside massive stars during their final stages of evolution or when these stars explode as supernovae. The explosion scatters the freshly produced matter into the interstellar medium from which new stars and planetary systems were formed.

Figure 10 is an Earth-based photograph of the Crab Nebula in Taurus, the remains of a supernova. What is the relative contribution of nonviolent nucleosynthesis in the stars as opposed to explosive nucleosynthesis in supernovae? How did the ultraheavy elements from iron to uranium and beyond form? Was the rate of element formation constant throughout the lifetime of the galaxy, or was there a tremendous outburst of activity in the first billion years after its formation? What is the origin of the light elements lithium, beryllium and boron? The approach to this objective is summarized in Table 12*.

Table 12

Approach to Objective 093

THEME 09 OBJECTIVES	QUESTIONS	SPACECRAFT INSTRUMENTATION
091 NATURE OF STELLAR EXPLOSIONS 092 NATURE OF BLACK HOLES	HOW MUCH DEUTERIUM WAS FORMED IN THE BIG BANG?	– MODEST UV TELESCOPE, LST GROUND-BASED RADIO TELESCOPE
093 WHERE AND HOW WERE ELEMENTS FORMED?	HOW AND WHERE DID ELEMENT FORMATION IN GALAXIES TAKE PLACE?	– MICROWAVE VLBI – 2 TO 6 METER TELESCOPES
094 WHAT IS THE NATURE OF COSMIC RAYS?	WHAT FRACTION OF MATTER HAS BEEN RETURNED TO INTERSTELLAR MEDIUM NONVIOLENTLY?	– MODEST UV TELESCOPE – SOLAR WIND MONITORS – MODEST SOLAR TELESCOPES
	HOW WERE ELEMENTS HEAVIER THAN IRON FORMED?	– LARGE X- AND GAMMA-RAY DETECTORS, GROUND-BASED RADIO TELESCOPES, LST, GRAZING INCIDENCE X-RAY TELESCOPES, HIGH ENERGY INSTRUMENTS ON SPACELAB, HEAVY COSMIC RAY DETECTOR
	HAS ELEMENT FORMATION BEEN CONSTANT THROUGHOUT THE LIFE OF THE GALAXY?	– 2 TO 6 METER TELESCOPES
	WHAT IS THE ORIGIN OF VERY LIGHT ELEMENTS?	– MODEST UV TELESCOPES – 2.4 METER TELESCOPE – HIGH ENERGY CLUSTER, SOLAR GAMMA-RAY MONITOR

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*Tables such as Table 12 are shown for a representative portion of the Objectives in Themes 8 through 12. The *"Questions" portion of such tables are shown in the text for the other objectives.*

Figure 10. The Crab Nebula, Remains of a Supernova

Objective 094 – What Is the Nature of Cosmic Rays?

The highly accelerated particles observed near Earth – the cosmic rays – include all the nuclei in the periodic table of the elements, as well as electrons and positrons. The great interest in these particles comes from the fact that the cosmic rays provide the only sample of matter that reaches us directly from outside the solar system, and, moreover, from the fact that during or after their nucleosynthesis, the particles have been accelerated to energies higher than those achievable in any terrestrial accelerator.

At present, the charge composition of the cosmic rays is known from hydrogen to iron, and in a somewhat fragmentary manner, for elements heavier than iron. In the energy range above about 1 GeV, the measurements were carried out solely by balloon-borne detectors; considerable discrepancies exist among the data of various groups. Nonetheless, we already know that the abundance distribution of the cosmic rays clearly points to an origin associated with massive stellar deaths.

Today, the major observational questions are: What are the mechanisms that accelerate the cosmic rays to their fantastically high energies? Does this acceleration take place during nucleosynthesis or are the cosmic rays accelerated from a previously nucleosynthesized matter? How are the cosmic rays distributed in the galaxy and what is their effect on galactic dynamics? Is there a hitherto undetected low-energy cosmic ray component which cannot penetrate into the solar system, but which has profound effects on the ionization and heating of the interstellar medium? Do the cosmic rays contain anti-matter?

This objective will involve measurement of the elemental isotopic and characteristic gamma-ray line emissions that accompany the nucleosynthesis processes. This will require accurate measurements of:

- Energy, mass, and charge spectra of cosmic-ray nuclei from hydrogen to uranium and possibly beyond.
- Energy spectra of cosmic-ray electrons and positrons.
- Energy spectra and elemental and isotopic composition of low-energy nuclei and electrons *in situ* in the interstellar medium.
- Energy spectra and elemental and isotopic composition of solar energetic particles.
- Measurement of the past abundances in old stars and galaxies using space telescopes and, in the solar system, by studying meteoritic and planetary samples.
- Measurement of the current abundances in the interstellar medium, using space telescopes and low-energy cosmic rays.

THEME 10: The Life Cycle of the Sun and Stars

The stars seem immutable but they are not. Like living organisms, they are born, evolve, and die. Our Sun, an average star, was born about 5 billion years ago and will probably die as a white dwarf about 5 billion years from now.

The life story of a star begins when a cloud of gas and dust becomes dense enough to start shrinking under its own gravity. When it is compressed to such high density and temperature that nuclear reactions start, the star begins to shine. When all the fuel is burned, depending on the size of the star, it either dies as a white dwarf or explodes as a supernova which may result in a neutron star or a black hole. Out of the material sprayed around the galaxy by the explosion, somewhere else a new star is born.

The study of the life cycle of the stars, therefore, should include the understanding of the composition and dynamics of the star both on a short-term and long-term basis, and the loss of matter from the star by mechanisms like solar and stellar wind. These areas of investigations can be grouped around the following questions, stated as objectives:

Objective 101 – What are the Composition and Dynamics of Interstellar Matter?

As a result of ground-based research and the observations from space telescopes, we have learned a great deal about interstellar matter. We now know that it is far from uniform. In some regions, the material is quite tenuous, and dust is rare. The gas is mainly in the form of ionized hydrogen and atoms heavier than helium which have lost several electrons. The temperature is high, sometimes close to a million degrees. In other regions, there is sufficient dust to protect the hydrogen atoms from the radiation from hot stars and cosmic rays. In these regions, which have been well studied by means of radio telescopes, the hydrogen is predominantly neutral. We have also learned that there are other regions in which the dust is very much more concentrated. In these regions, the hydrogen occurs almost completely as molecular hydrogen and, in the denser of these regions, we find other molecules such as carbon monoxide and CH. With increasing density, not only are there more diatomic molecules, but also increasingly complex organic molecules.

The interstellar medium is therefore very complex, consisting of several coexisting gaseous phases, molecules, grains, magnetic fields, and cosmic rays. What are the interactions among all these components? How is the interstellar matter heated and ionized? How are molecules formed? How do cosmic rays propagate? What is the chemical and isotopic composition of interstellar matter? How do supernovae interact with interstellar matter? Some important measurements to determine the properties of the interstellar medium should include:

- Visible observations and space infrared observations of the grains
- Ultraviolet observations of chemical and isotopic abundances in the interstellar matter

- *In situ* measurements of the low-energy cosmic rays which may heat and ionize the interstellar medium
- High-energy cosmic-ray observations to study the propagation and anisotropy of the cosmic rays
- X-ray observations of the hot components of the interstellar medium
- Gamma-ray observations of the cosmic ray interactions with interstellar matter, including molecules
- Radio, infrared, and ultraviolet observations of molecules and detection of complex molecules

Objective 102 – Why and How Does Interstellar Dust Condense Into Stars and Planets?

Although the general picture of stellar formation appears clear, there are important questions remaining: How extensive must density fluctuations be to initiate gravitational collapse? What keeps turbulent motions from disrupting such a collapse? What happens to the kinetic energy in this turbulence? These questions have a direct relationship to more obviously interesting questions: What determines whether a dust cloud condenses into a single star, a multiple star system, or a single star with planets? In the latter case, what determines the number, size, and spacing of the planets? Obviously, any estimate of the number of inhabitable planets in the galaxy must be based on the answers to these two last questions. Both space and ground-based observations must continue to contribute to these studies.

Before dust can condense into a star, it must be quite cold. The most efficient cooling mechanisms are probably infrared emissions from atoms and molecules. These can be observed only from space. The infrared can identify regions of star formation which had escaped notice because of the obscuration of the dust. Figure 11 is a pictorial representation of an infrared scan made by a space instrument of a star that may be in the process of formation and Figure 12 is a schematic of this phenomenon. With a better knowledge of the number of stars being formed, we can better understand the current state of evolution in our galaxy.

For the study of the actual birth of a star, infrared spectrometers on medium-size telescopes and submillimeter receivers on moderate-size antennae (~ 10 m) can provide substantial information on the occurrence on line emission in regions of star formation. Modest-size infrared survey telescopes can detect newly forming regions. Michelson and long baseline interferometry in both the infrared and the submillimeter region can "image" the distribution of interstellar dust and gas in regions in which stars are forming, while high spectral resolution coupled with the spatial resolution will permit a study of the kinetics of the region. The approach to pursuing this objective is shown in Table 13.

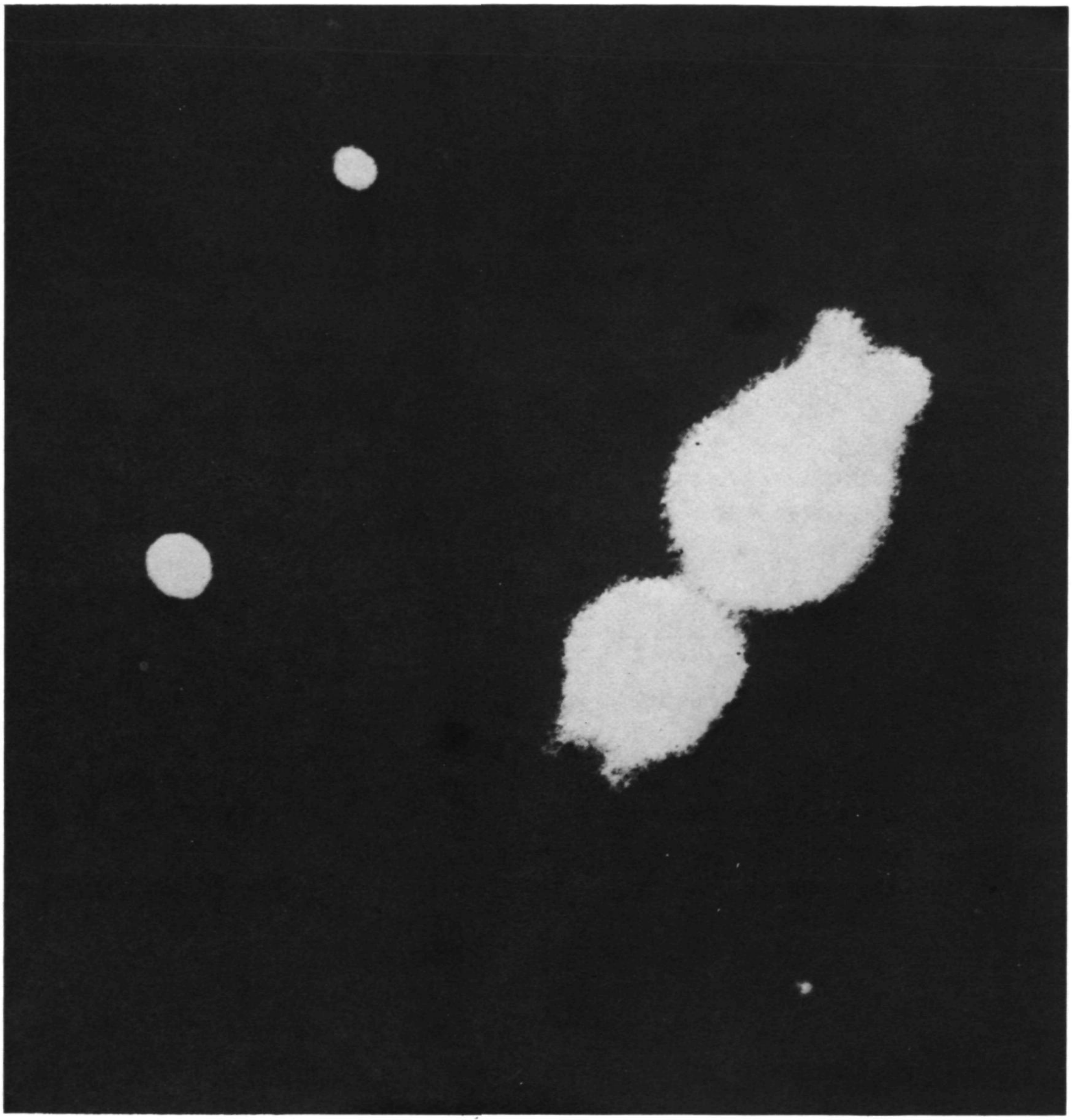

Figure 11. Detection of Unseen Star by Infrared Instruments in Space

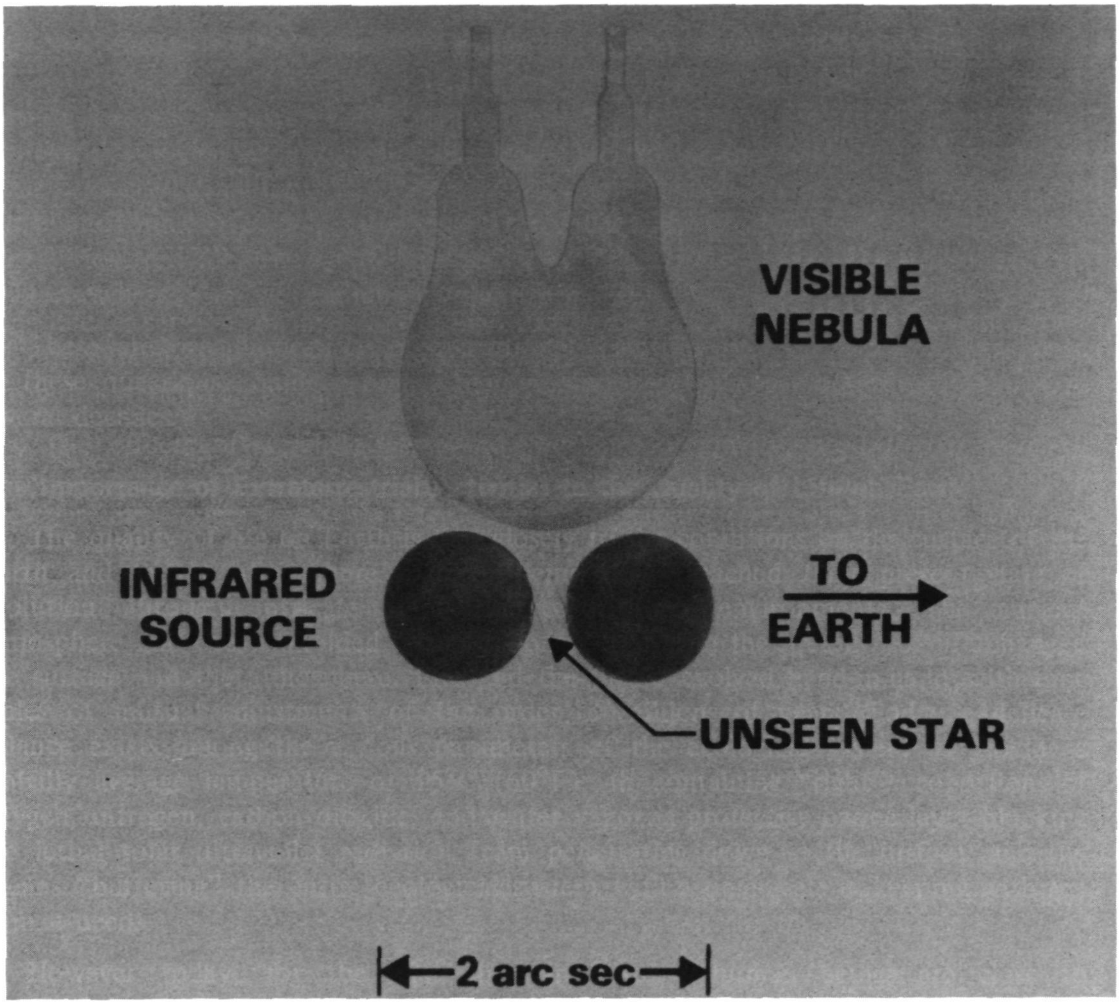

Figure 12. Schematic Model of Egg Nebula System

Table 13

Approach to Objective 102

THEME 10 OBJECTIVES

101 COMPOSITION AND DYNAMICS OF INTERSTELLAR MATTER

102 WHY AND HOW DOES INTERSTELLAR DUST CONDENSE INTO STARS AND PLANETS?

103 NATURE AND CAUSE OF SOLAR ACTIVITY

104 CORONA AND INTERPLANETARY PLASMA

105 WHAT IS THE ULTIMATE FATE OF THE SUN?

QUESTIONS	SPACECRAFT INSTRUMENTATION
WHAT INITIATES THE COLLAPSE OF A CLOUD?	– IR INTERFEROMETER – MICROWAVE LBI
WHAT ARE THE COOLING MECHANISMS INVOLVED?	– IR SPECTROMETERS – LARGE AMBIENT IR TELESCOPE – LARGE CRYOGENIC IR TELESCOPE
WHAT DETERMINES WHETHER A CLOUD COLLAPSES INTO A SINGLE STAR, A MULTIPLE STAR SYSTEM, OR A SINGLE STAR WITH PLANETS?	– IR INTERFEROMETER – LARGE CRYOGENIC IR TELESCOPE – IR SPECTROMETERS – MICROWAVE LBI
WHAT IS THE CURRENT RATE OF STAR FORMATION?	– IR CRYOGENIC SURVEY TELESCOPE – LARGE CRYOGENIC IR TELESCOPE
WHAT KEEPS TURBULENCE FROM DISRUPTING THE COLLAPSE AND WHAT HAPPENS TO THE KINETIC ENERGY IN THIS TURBULENCE?	– IR SPECTROMETERS – MICROWAVE LBI – IR INTERFEROMETER

Objective 103 – What Is the Nature and Cause of Solar Activity?

In some unknown way, the energy which is transferred convectively in the Sun into a layer just below its visible surface is transformed into a wide variety of solar activity. This includes sunspots, solar flares, coronal streamers, chromospheric arches, and the solar wind (interplanetary plasma). Appreciable X-ray radiation is generated and, in strong outbursts, gamma rays have been observed. The latter indicate that nuclear reactions are taking place. Not only are the short-term details unknown, but it is not understood why activity waxes and wanes in an 11-year cycle, with the polarity of the magnetic fields generated reversing at the conclusion of each cycle. The question has become more complex recently when it was realized that in a 75-year period in the 1700s, no sunspots were recorded; that is, "activity" was minimal. This period coincides with a mini-Ice Age in the terrestrial Northern Hemisphere. Clearly, it is important to understand this phenomenon with its potential for considerable impact on human life.

The detailed description of the mechanism which triggers solar flares is not available. Accelerated particles from the flare are observed directly in the interplanetary medium. Questions remain as to the true physical conditions within a flare and of the relationship between solar flares and other violent cosmic phenomena such as stellar flares or supernovae.

A comprehensive study of the solar activity can be carried out by 600-kg satellites in Earth-orbit. Attached to modest-size telescopes, various types of photometers and spectrometers, as well as polarimeters, are required. Large telescopes will be needed for very-high spatial resolution of the solar disk in various wavelengths. Modest instruments in solar polar orbit will investigate a phase of solar activity not observable from the vicinity of the Earth. X-ray and gamma-ray instruments are also needed for long periods in space. Low-frequency radio receivers near the Earth or Moon can trace the paths of particle bursts from the active regions to near the Earth. The approach is displayed in Table 14.

Table 14

Approach to Objective 103

OBJECTIVES

101 COMPOSITION AND DYNAMICS OF INTERSTELLAR MATTER
102 WHY AND HOW DOES INTERSTELLAR DUST CONDENSE INTO STARS AND PLANETS?
103 NATURE AND CAUSE OF SOLAR ACTIVITY
104 CORONA AND INTERPLANETARY PLASMA
105 WHAT IS THE ULTIMATE FATE OF THE SUN?

QUESTIONS	SPACECRAFT INSTRUMENTATION
STRUCTURE AND DYNAMICS OF CONVECTIVE ZONE	SECTOR BOUNDARY MEASUREMENTS, XUV OR SOFT X-RAY PICTURES OF SOLAR FIELD CONFIGURATION, HIGH RESOLUTION MAGNETIC FIELD MEASUREMENTS, THEORETICAL MODELS
POLAR MAGNETIC FIELDS	OUT-OF-ECLIPTIC OBSERVATIONS WITH MAGNETOGRAPH, PHOTOHELIOGRAPH EUV/XUV TELESCOPES AND WHITE LIGHT CORONAGRAPH
ORIGIN OF SOLAR CYCLE	LONG-TERM SOLAR PATROL OF PHOTOSPHERE, CHROMOSPHERE, INNER AND OUTER CORONA AND OF MAGNETIC FIELD
SEARCH FOR TRIGGER MECHANISM (ENERGY STORAGE IN MAGNETIC FIELDS, SIGNS OF ONSET OF INSTABILITIES)	MAGNETOGRAPH (VISIBLE LIGHT TELESCOPE) PLUS UV, EUV AND SOFT X-RAY TELESCOPES
ACCELERATION OF CHARGED PARTICLES IN SOLAR FLARES	GROUND-BASED MICROWAVE DETECTORS HARD X-RAY AND GAMMA RAY DETECTORS IN SPACE WITH HIGHEST SPATIAL AND TIME RESOLUTIONS

Objective 104 – Corona and Interplanetary Plasma

The corona is a hot gas situated on top of the cooler photosphere of the sun. The high temperature comes from mechanical energy in the convection zone, but how is this energy transported? What occurs in the polar regions of the sun? What is the nature of the various events such as radio bursts, shocks, and streams of charged particles, and the newly discovered coronal holes?

Studies of space derived data have revealed the sources of three different types of high-velocity streams in the interplanetary plasma. Solar flares and coronal transients are now recognized as the sources of non-recurrent streams. Coronal holes are associated with recurrent streams, but the accelerating mechanism is unknown. Is temperature the critical parameter or is it the outward propagation of some form of waves?

The sun emits both high- and low-energy particles at all times. The low-energy particles travel approximately along the solar magnetic field; high-energy protons propagate radially outwards. During the solar storms and flares, the energy spectrum and energy flux of the particles vary and, at the same time, the structure of the solar and interplanetary field may change as well, making understanding of the conditions of the interplanetary medium a complex problem in plasma dynamics. The transfer of energy and mass from the interplanetary medium into the planetary magnetosphere is highly dependent on the configuration of the planetary magnetic field as well as of the interplanetary plasma. Questions still remaining include: What is the structure of the magnetic field near the sun? What is the origin of the sector structure and what causes the changes in this structure? How do solar "gusts" propagate relative to the more steady wind? How does the material from solar radio bursts propagate through the interplanetary medium? What are the relations between the thermal and the cosmic ray particles? Continued investigation of the corona and interplanetary plasma will require:

- Empirical definition of magnetic field, temperatures and density structures of the chromosphere and corona using visible and radio telescopes, and ultraviolet and soft X-ray detectors in space.
- Definition of the location of the source of the interplanetary plasma by simultaneous measurement of ionization states of elements in the plasma by particle detectors, and in the corona by ultraviolet and extreme ultraviolet telescopes. Also required are further observations of the corona from spacecraft positioned around the ecliptic.
- Study of the mechanism of solar wind acceleration by theory and by measurement of elemental and charged state abundances in the corona.
- Study of the polar regions of the sun from an out-of-the-ecliptic mission.
- Measurement of coronal temperature using Lycoronagraphs on in-ecliptic and out-of-ecliptic spacecraft.
- Study of particle bursts as they move out from the sun to the vicinity of the Earth, by means of low-frequency, directive, radio receivers.

Objective 105 – What Is the Ultimate Fate of the Sun?

The energy of the sun is believed to be generated in its interior from fusion reactions in which four hydrogen nuclei combine to form a helium nucleus with the excess mass being transformed into energy. This energy is produced as gamma rays and neutrinos; the gamma rays are then steadily degraded as the energy moves out from the interior until it emerges from the photosphere in the form of light, predominantly. The proof of the validity of our theory would be the detection of the flux of neutrinos which would emerge from the Sun essentially unchanged, and which should reach the ground equally unmodified. However, to date, the experimentally established upper limit to this flux is incompatible with theoretical predictions, implying that our physical concepts are incorrect. Further, more sensitive experiments are planned in order to determine the true value of the neutrino flux, if indeed such a flux exists.

Although we know the general course of evolution for the Sun, we do not know how steady the energy production is. Very small changes in the temperature where these nuclear reactions occur lead to great changes in energy production and hence in neutrino flux. We know that no very large changes in energy production have taken place over the past billion years but are there small changes? In other words, is the solar constant really constant? Even small changes (of the order of 1%) in the amount of energy reaching the Earth can have major impact on our climate.

In time, the center of the Sun will run out of hydrogen and the nuclear "burning" will be forced to move out to a shell surrounding the nucleus, where hydrogen is still available. Later, the center will become hot enough that the helium atoms can fuse to form carbon and oxygen. In the meantime, the Sun will have become much larger and noticeably cooler. Eventually, the helium at the center also will be exhausted. The Sun will start to contract and become hotter until it settles down as a very hot, very small star. Finally, it will cool into a cold body detectable only by its gravitational attraction on its family of planets. Although the general picture of this evolution is well understood, many questions remain. As Figure 13 illustrates, the Sun can be studied from space in ways that are impossible from Earth. White dwarfs (the hot stage at the end of the contraction) are difficult to find because of their faintness; their physics is still not well understood. We observe no stars which are contracting on their way to white dwarfs among the nearby stars, although we do observe them in the galactic halo and globular clusters. Why? How many black dwarfs (contracted stars which have cooled) are there? They can tell us the rate of star formation in the early era of our galaxy.

For the questions related to the validity of the nuclear synthesis theory, the neutrino detection experiment is crucial although it is not clear whether space observations will help. The steadiness of the solar energy output, however, can be monitored with small, very well calibrated detectors in space laboratories. Ultraviolet telescopes will facilitate the study and detection of white dwarfs; black dwarfs will be comparatively bright in the infrared. Moderate-to-large telescopes will be needed in both regions.

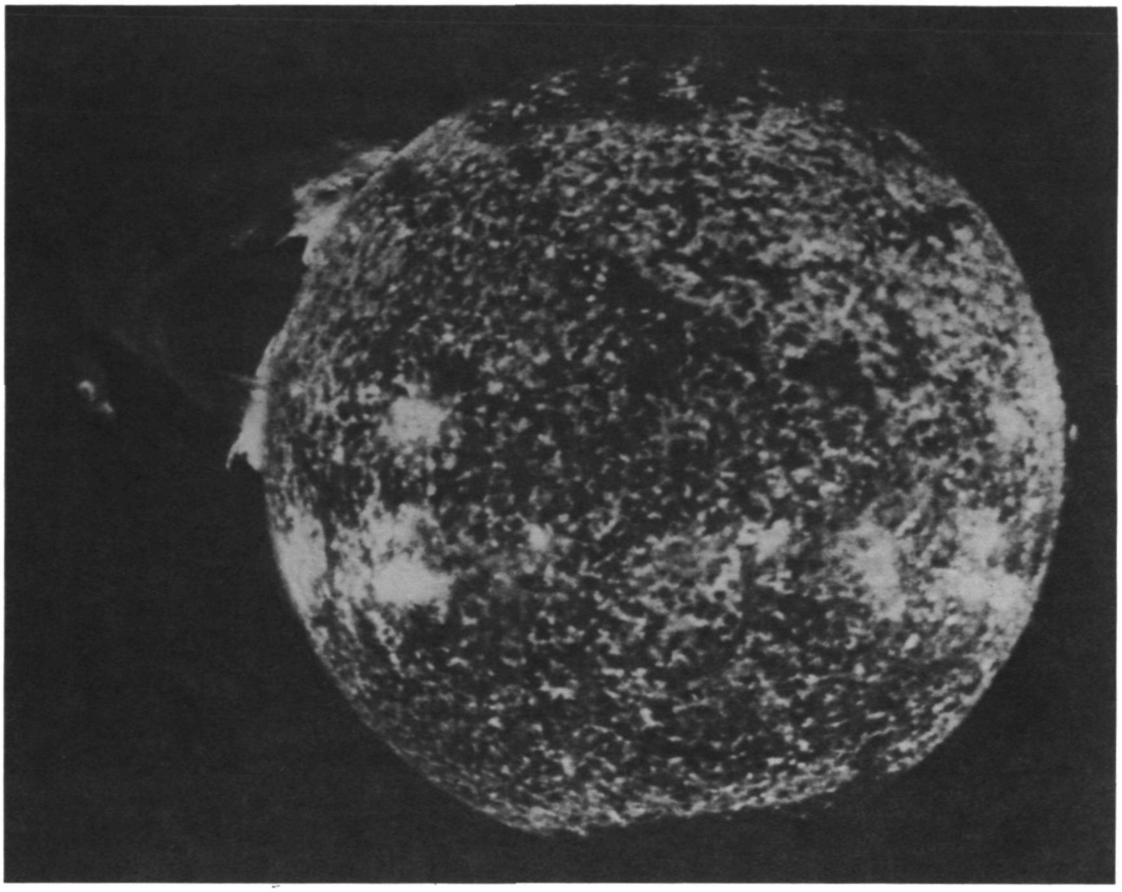

Figure 13. Skylab Photograph of Solar Phenomena not Observable from Earth

Pertinent questions relating to this objective include:

- What is the neutrino flux from the solar interior?
- Is the solar constant really "constant"?

Summary Observation on Theme 10

All of the questions of this theme related to the life cycle of the Sun and stars range from the processes which give birth to a star to its ultimate fate. The Sun, being a "middle-aged" star, provides information on only one period of stellar history. But young and old stars are abundant in the galaxy and a systematic study of the stars of various ages is essential to this problem.

Apart from its study as a representative star, the study of the Sun is important because solar energy is vital for life on Earth. A small change in luminosity could considerably alter the ecological cycle of the biosphere. It is for this reason that the questions related to the solar activity, corona, and the propagation of plasma through the interplanetary medium have been given special consideration in this Theme.

A wide variety of techniques will have to be employed to study phenomena as different as the composition of the interstellar medium, coronal holes on the sun, and plasma near the Earth.

THEME 11: The Evolution of the Solar System

We are at a unique point in history with regard to exploration of the solar system. What 20 years ago was a neglected field of astronomy is now in the forefront of science as a result of its accessibility for detailed study via spacecraft whose successful missions to the Moon and neighboring planets have already demonstrated major advances.

Objective 111 – What Process Occurred During Formation of the Solar System?

As we look ahead to the last quarter of the 20th century, we can see the possibility of exploring many of the bodies in the solar system, including the Sun, planets, satellites, asteroids, and comets; and of having the capability of utilizing a wide variety of spacecraft missions to answer some of the important scientific questions. Indeed, such capability is needed if we are to provide clues to such fundamental questions as the origin of the solar system and the evolution of solar system bodies, including our own Earth, through a comparison of their present and past properties.

Aside from its fundamental scientific importance, a study of other planetary environments may ultimately be of practical importance for our planet, in helping us better understand the factors that control the dynamics of Earth's crust, oceans, and the atmosphere.

Development of the solar nebula has long been pictured as the result of the collapse of a large interstellar cloud whose inner portion was then heated by absorption of infrared radiation emanating from the proto-sun. The heat vaporized much of the nebula, except perhaps the outer portions, and condensation occurred during ensuing periods of cooling. The mixture of gas and condensed particles formed a disk with the solid particles being concentrated in a thin central disk. The composition of the condensate was controlled by the temperature gradient within the nebula.

Assuming extensive vaporization and local homogenization of condensates, the compositions of planetary bodies can be calculated at various points along the temperature gradient. However, the major question to be answered is: Can the sequence of planets and satellites be explained by a process of thermochemical fractionation alone? Other problems in this field involve the time required for formation and condensation of the nebula, the relative times of formation of the sun and planets, and the mass of the initial nebula. Although these are important questions, verification of the thermochemical equilibrium model would provide a major step toward answering these other questions.

Once the condensates have formed, the next step is their accretion into planets. A recent model shows that gravitational instability may cause concentration of particles and can account for the growth of numerous solid objects up to 0.1 km in diameter within a very short time (~ 1 year) without calling on special sticking forces. The same process would be reiterated over a few thousand years to form a second generation of planetesimals up to a few kilometers in diameter, or if some of the clusters interpenetrate, the solid masses may be even larger. The final stages in the development of planet-sized objects are still not known.

The major problem in this field is the location of material that represents various stages in the aggregation process before that material has undergone modification by melting, or other processes. Comets may represent nonaggregated material. Some of the various types of meteorites may represent early stages of aggregation, and asteroids may represent intermediate stages.

Understanding the origin of a planet requires not only knowledge of its initial composition, but also the distribution of the composition, initial internal temperature distribution, time of formation, and its relation to other bodies in the system as discussed earlier. This requires extrapolation of information from rock samples that retain products from various stages during the evolution of the planet. Therefore, most of the pertinent data relating to the origin of terrestrial planets should result from interpretations of their evolutionary history and extrapolation to the initial state. As for the outer planets, we wish to distinguish between two alternative models of the formation of Jupiter and Saturn. On the one hand, there may have been a two-stage process involving, first, the formation of a sufficiently massive solid core of material, followed by the aggregation about it of nearby gas. Alternatively, they may have formed in a one-step process, as stars are thought to form, in which an initial density perturbation is accentuated and results in a gaseous condensation. A related question is whether Uranus and Neptune, which surely have cores, originated in a similar fashion to Jupiter and Saturn.

We also seek to understand the processes of fragmentation and agglomeration that have led to the formation of the satellites, the asteroid belt, and comets. In trying to understand the origin of satellites, it is useful to try to determine the reasons for the differences among satellite systems. For example, why are there so few natural satellites of the terrestrial planets which we have already visited with our spacecraft as shown in Figure 14, as compared with those of Jupiter and beyond, that is with the number for the Jovian planets? The rings of Saturn may be a unique "fossil" of a phase in the development of satellite systems and studies of their physical properties may provide clues to the conditions at a point in the distant past. The asteroids and comets may represent examples of material that formed in regions that had no large central object, such as a planet. Thus, they may represent an intermediate stage in the formation of planet-satellite systems.

Lastly, the major questions remaining to be answered for the Moon are its initial composition, whether it was homogeneous or layered, the origin of an early lunar magnetic field, and the location of its origin. After Apollo, we are more or less certain that it did not fission from the Earth, but then, where it did form remains a puzzle.

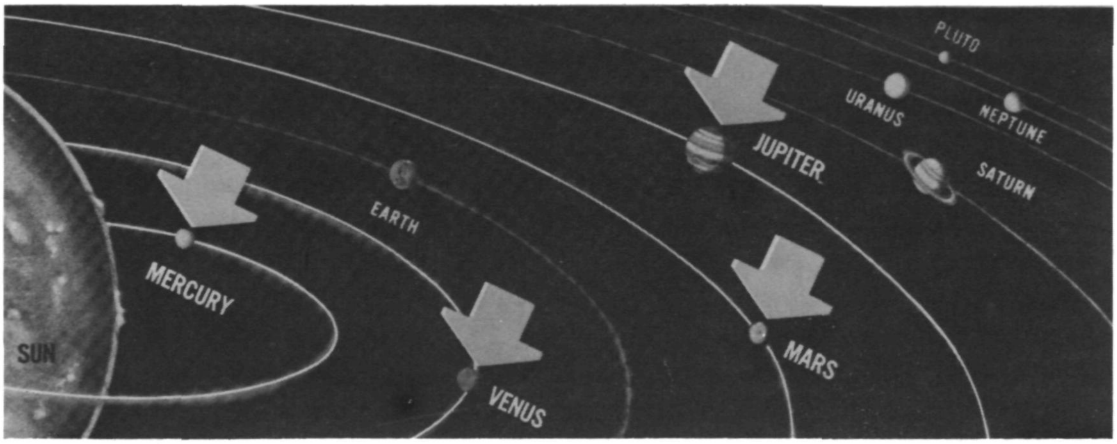

Figure 14. Planets Already Visited by U.S. Spacecraft

A comparative study of both the terrestrial and outer planets involving bulk composition, internal structure, and the ages of these bodies should form the basic elements of a program. Simultaneously, a search for the most primitive material should also commence. Precise measurements of the moment of inertia of the outer planets, magnitude of heat flow in the terrestrial planets, and accurate abundances of elements in the atmospheres are some of the characteristic measurements which need to be made in order to understand the rates of evolution of different bodies.

Objective 112 – How Do Planets, Large Satellites, and Their Atmospheres Evolve?

The most far-reaching discovery during the past decade of planetary exploration is the extensive chemical and physical evolution that essentially all planetary bodies have undergone since their formation. Previously the Earth was widely regarded as unique in this respect. The Moon was considered as a primitive undifferentiated body – a direct sample of original solar system material. Instead, it is now clear that the Moon, Mars, Mercury, Venus, and probably some satellites of the Jovian planets, some asteroids, and the parent bodies of some meteorites, are all chemically differentiated. Comparison of available data indicates that the Moon completed essentially all of its evolution billions of years ago and is the least differentiated planet, with Mercury a close second.

Although gross fractionations of large bodies may be implied by remote sensing of their surfaces, lunar sample experience makes it clear that quantitative interpretation of ages, chemical components, temperatures, and processes of fractionations requires detailed and correlated textural, chemical, and isotopic studies.

As for the atmospheres, the problems relate to original atmospheric components, gases introduced by devolatilization during fractionations, and respiration by living organisms. The relations and timing of these three sources of atmosphere are major questions in planetary evolution. Eventually these trends must be compared for each planet or satellite.

While outgassing from the interiors of the terrestrial planets appears to be the chief source of their current atmospheres, we still do not have a feeling for the relative importance of the other sources. These may include even occasional cometary impacts and the partial retention of whatever atmospheres they possessed at the time they formed.

Finally, the question of loss of gases from a planet is of considerable interest. How much of the atmosphere escapes from the top and how much is bound into the surface through chemical reactions are two very significant questions we have been asking about the terrestrial planets in order to explain their current atmospheres, which are so different from that of the Earth. The approach to this objective is summarized in Table 15.

Table 15

Approach to Objective 112

THEME 11 OBJECTIVES	QUESTIONS	SPACECRAFT INSTRUMENTATION
111 WHAT PROCESSES OCCURRED DURING THE FORMATION OF SOLAR SYSTEM? 112 HOW DO PLANETS, LARGE SATELLITES AND THEIR ATMOSPHERES EVOLVE?	DID PLANETS UNDERGO CHEMICAL FRACTIONATIONS? WHEN? HOW?	– PENETROMETERS TO MARS, MERCURY, VENUS, TITAN – ORBITERS TO MARS, MERCURY, VENUS, MOON, TITAN (REMOTELY SENSED CHEMISTRY) – SAMPLE RETURNS FROM MARS, MERCURY, VENUS, ASTEROIDS, LUNAR HIGHLANDS
113 HOW CAN ATMOSPHERIC DYNAMICS BE QUANTIFIED?	WHAT WAS THE MOON'S INITIAL COMPOSITION AND MAGNETIC STATE?	– LUNAR POLAR ORBITER, SAMPLE RETURNS FROM HIGHLANDS, LUNAR PENETROMETER (HIGHLAND HEAT FLOW)
114 ORIGIN AND HISTORY OF MAGNETIC FIELDS	WHAT DETERMINES CRUSTAL MOTIONS?	– ORBITERS TO VENUS, MARS, MOON, MERCURY WITH IMAGING AND TRANSPONDERS (GRAVITATIONAL ANOMALIES) – HARD LANDERS (LOCAL CHEMICAL AND MAGNETIC ANOMALIES)
	DID PLANETS HAVE INITIAL ATMOSPHERE AND DOES ANY OF IT REMAIN?	– ENTRY PROBES ON JOVIAN PLANETS AND MARS, VENUS (MASS SPECTROMETER)
	WHY THE TERRESTRIAL PLANETS TOOK SUCH DIVERGENT PATHS IN ATMOSPHERIC EVOLUTION?	– LOW ORBITERS, ENTRY PROBES, LANDERS (MARS, VENUS)
	DOES OUTER SOLAR SYSTEM REPRESENT PRIMORDIAL MATERIAL?	– ENTRY PROBES TO JOVIAN PLANETS AND MAJOR SATELLITES, COMET SAMPLES

Objective 113 – How Can Atmospheric Dynamics Be Quantified?

The Mariner and Pioneer missions, together with ground-base photography, have shown that there are very high velocity winds near the cloud tops of Venus; that, on occasion, planet-wide dust storms can occur on Mars; and that Jupiter's Red Spot may be a long-lived storm. Both U.S. and U.S.S.R. flights to Venus indicate the greenhouse effect to be the most likely model of the surface to explain the abnormally high temperature.

To convert meteorology from a quasi-empirical science dealing with the dynamics of the Earth's atmosphere into a science whose basic principles are better understood, we must apply these principles to a number of other atmospheres and evaluate the importance of various factors that determine climate and weather. Among the factors of interest are the rate of rotation of the planet, the way solar energy is deposited in the atmosphere and at the surface, and the role of condensation clouds. By studying the dynamics of Venus, Titan, Mars, the Earth, and Jupiter, we span a large range of rotation periods. Condensation clouds are present over all of Venus, half of Jupiter, and very little of Mars. These atmospheres also provide strong contrasts in the place of deposition of the solar energy. By understanding the theoretical basis of planetary meteorology better, we can hopefully begin to disentangle the complexities of terrestrial weather and climate.

Entry probes offer the most important method for attacking this problem by supplying *in situ* information on the wind velocity profile, solar energy deposition profile, and the sources of infrared opacity. For Venus and the outer planets, useful information on the flow patterns near the cloud tops can be outlined from synoptic television coverage from an orbiter, and even from large telescopes in Earth orbit.

In the case of Mars, surface wind measurements obtained from landers could supply some very important information. We noted that direct wind velocity measurements are probably the single most useful meteorological measurement. Elements of a program to attack this problem include orbiters for Venus, Mars, and Jupiter, and penetrators on Mars, Venus, and Titan.

Pertinent questions which we need to answer include:

- What is the driving force for atmospheric motions?
- What are the patterns of motions and their causes?
- What are the magnitudes of wind speeds and temperature variations?
- How sensitively does a climatic regime depend on the various driving forces?

Objective 114 – Origin and History of Magnetic Fields

Spacecraft missions indicate a dipolar magnetic field closely aligned with the axis of rotation on Mercury, a weak dipolar field on Mars, and no magnetic field on Venus or the Moon. However, rock samples from the Moon show that a moderately-strong magnetic field existed over most of the first 1.5 billion years of lunar history. Over the last two decades, studies of remnant magnetization in terrestrial rocks have shown a long history of reversals of the Earth's magnetic field, large variations in its intensity, and changes in the pole positions. Recent U.S. spacecraft have confirmed the prior inference drawn from ground-based radio observations: Jupiter has a strong magnetic field and a massive magnetosphere containing high-energy particles analogous to the Earth's Van Allen belts. However, surprisingly, the outer portion of Jupiter's magnetosphere has a disk-like shape and Jupiter is a major source of high-energy particles for the rest of the solar system.

Comparative planetary studies are major elements of a program to answer the questions regarding the magnetic field. The type of mission involved would be fly-bys of Saturn, Uranus, and Neptune; orbiters of Mars, Mercury, Venus, and Jupiter; and sample returns from Mars, Mercury, and Venus. Also, the measurement of magnetic field and its polarity at different locations in the interplanetary medium, both in and out of the plane of the ecliptic, will throw light on the nature of the solar field.

Three major questions remain to be answered: Is the basic mechanism for the origin of planetary magnetic fields a dynamo process generated in the molten core of a rotating planet? What role does the magnetic field play in determining the interaction of a planet with the interplanetary medium? What can we learn about the history of a planet from the remanent magnetic fields?

Questions believed to be pertinent to this objective are:

- What is the intensity and orientation of present planetary magnetic fields?
- What was the intensity and orientation of past planetary magnetic fields?

THEME 12: Origins and Future of Life

Our concepts of the origin and nature of life have evolved remarkably in the past few decades. It now appears that life arose spontaneously from chemical precursors which abounded in the ocean and in the atmosphere during the early years of our planet.

Four major discoveries from four different fields of science have allowed us to formulate this theory. First, biologists have shown that all living organisms on the earth are composed of a few varieties of chemical compounds, like amino acids, carbohydrates, fatty acids, purines, and pyrimidines. The genetic codes of all organisms comprise nearly identical nucleotides put together in different sequences to form DNA. Second, chemists have succeeded in synthesizing these same building blocks from simple compounds such as nitrogen, ammonia, carbon dioxide, methane, and hydrogen: the conditions of synthesis were those thought to resemble conditions that existed on the Earth when the planet was formed. Third, paleontologists and organic geochemists have produced convincing evidence for the existence of microfossils and biochemical debris more than three billion years old, moving the time when life began back to the early history of the Earth. Fourth, scientists have observed a number of different types of organic molecules in the vast expanses of the interstellar space, and in meteorites which have fallen on the Earth. The processes responsible for the synthesis of the building blocks of life are clearly widespread in the Universe. The processes are described collectively by the term "chemical evolution."

That life evolved out of inanimate matter on the surface of the Earth some 3.5 billion years ago is now a generally accepted idea. The major gap in our understanding is the evolution of the replicating cell.

It is postulated also that life may have arisen in a similar fashion on the planets of large numbers of stars in the galaxy where the solar and planetary characteristics are favorable; indeed, it has been suggested by many that the emergence of life is inevitable if the right conditions exist. In many cases, this life may have developed to the stage of intelligence, with a civilization far in advance of our own. We wonder what such societies are like, and whether we can communicate with them. These questions form the substance of the examination of the origin and future of life that follows.

Objective 121 – How Did Life on Earth Originate?

The Earth is the only known habitat of the phenomenon of life, although we suspect that there are many other planets in the Universe where life also occurs. Man's concern with his origin and his uniqueness in the Universe has profound philosophical and scientific consequences, shaping his thinking about the planet he lives on as well as his own place in the cosmos. This question is closely aligned with that of life elsewhere in the solar system and beyond. In addition, understanding the origin of life on Earth necessarily means understanding the early history of the Earth in terms of physical, chemical and geological processes.

Laboratory studies strongly suggest that life began as the result of a process of chemical evolution in which the primitive terrestrial molecules reacted chemically to form simple, then increasingly complex organic molecules until a simple, self-replicating system and which we might call "alive" was produced. This began the chain of biological evolution. Study of the oldest (pre-Cambrian) rocks on Earth suggests that life, in simple form, was already present on the Earth 3 to 4 billion years ago, and perhaps earlier, indicating that chemical evolution may have proceeded rapidly. Is this how life began on Earth? Elsewhere?

In our attempt to understand what really happened on Earth during the first billion years, when life apparently originated, it is important that:

- Laboratory work in chemical evolution should continue to fill in the gaps of the early chemical sequences leading to life. This could involve the synthesis of "self-replicating" systems in the laboratory, but certainly the development of plausible chemical pathways which are consistent with the early physical history of the planet. Some modest simulation has been performed, but major efforts are in order.
- Work should continue with the oldest available records of the Earth in order to clarify the ambiguities in our present concepts of what actually happened on earth during its early evolution.
- The existing lunar samples and future planetary samples need to be studied to determine the characteristics of the solar flux at the time life originated on the Earth.

Objective 122 – Is There Extraterrestrial Life in the Solar System?

The impact of the detection of life elsewhere in the solar system or beyond would be felt in every aspect of human life – in our philosophical and religious concepts, our social interactions, and our scientific institutions. The science of biology would be established on universal principles as are physics and chemistry. Although the prospects for life in our own solar system do not seem overly optimistic, in the case of some planets and large satellites we cannot rule out the possibility of life forms. Laboratory investigations suggest that the processes which led to life on Earth (chemical evolution) should also have occurred on any planet with a similar history. Two questions have persisted since the beginning of civilization:

- Is life on the Earth a unique and special event?
- Is the Earth the only inhabited planet in the solar system?

We can remove these questions from the realm of philosophy and place them firmly within the domain of science with the assistance of this objective.

To search for extraterrestrial life in the solar system, living or extinct, major life detection missions would include return of surface samples from Mars; atmospheric probes to Venus, Jupiter, and Saturn; and the exploration of Saturn's satellite, Titan, by landers. Major experiments would involve precise analysis of the returned samples of Mars, atmospheric chemistry of Jupiter and Saturn, and close exploration of the surface of Titan.

Objective 123 – What Organic Chemistry Occurs in the Universe?

All life on Earth is based on organic molecules with water as a solvent. While we can speculate about other chemistries forming the basis of life structures and processes, we know of no such systems and indeed find it extremely difficult even to model such systems theoretically. Thus, life and organic molecules seem inextricably interwoven.

Laboratory work has demonstrated the inevitability of synthesis of simple and complex, biologically important organic molecules from simple precursors such as the components of the atmospheres of primitive planets or planets such as Jupiter and Saturn. Analysis of meteoritic material has demonstrated the presence of these same molecules (amino acids, fatty acids, etc.) apparently of non-biological origin, and the radio telescope is finding simple organic molecules in the vastness of interstellar space. Even lunar samples have yielded trace amounts of organic precursors.

The need is to unravel the details of this organic chemistry. Just how universal is this type of organic synthesis? How complex are the molecules being synthesized extraterrestrially? Where do the meteorites and their organics come from? How do we distinguish biological from non-biological organic matter?

This objective involves the following types of activities:

- Continued laboratory work is required to develop pathways of organic synthesis consistent with geophysical concepts.
- Simulation work is required to understand the mechanism of interstellar synthesis. Unambiguous criteria are needed to distinguish between biological and non-biological molecules (e.g., optical activity, isotope ratios, etc.), including continued radio telescope measurements, continued studies to determine the origin of meteoritic material, missions to return extraterrestrial samples to Earth for crucial analyses, and missions to the planets for *in situ* organic analysis.

The approach to this objective is summarized in Table 16.

Objective 124 – Do Other Stars Have Planets?

If our present theories about how stars and planets evolved are correct, many of the billions of stars should have planets in orbit around them in the same way as our own star. At the present time, however, we have no direct evidence that other planets exist, except possibly for the observed oscillations in the motion of certain nearby

Table 16

Approach to Objective 123

THEME 12 OBJECTIVES	QUESTIONS	SPACE AND GROUND INSTRUMENTATION
121 HOW DID LIFE ON EARTH ORIGINATE?	SIMULATED SYNTHESIS OF ORGANIC MATTER	– LABORATORY EXPERIMENTS UNDER PRIMITIVE EARTH CONDITIONS – LABORATORY EXPERIMENTS TO UNDERSTAND INTERSTELLAR SYNTHESIS
122 IS THERE EXTRATERRESTRIAL LIFE IN THE SOLAR SYSTEM?		
	METEORITE ANALYSIS	– AGE DATING, CHEMISTRY, TEXTURE (INITIAL CONDITION)
123 WHAT ORGANIC CHEMISTRY OCCURS IN THE UNIVERSE?	SEARCH FOR DEGREE OF CHEMICAL EVOLUTION IN VARIOUS BODIES OF THE SOLAR SYSTEM	– MARS LANDER-ROVER, SAMPLE RETURN FROM MARS, JOVIAN PLANETS' PROBES, TITAN LANDER, SAMPLING OF ASTEROIDS AND COMETS
124 DO OTHER STARS HAVE PLANETS?		
125 CAN WE DETECT EXTRATERRESTRIAL INTELLIGENT LIFE?	CONTINUED SEARCH OF MOLECULES IN INTERSTELLAR MEDIUM AND IN THE NEIGHBORHOOD OF OTHER STARS	– GROUND-BASED RADIO TELESCOPE – LARGE AMBIENT IR TELESCOPE

stars, which may be caused by one or more planets in orbit around those stars. Positive identification of such planets is needed to help confirm theories of planetary formation and also to support present day theories about the possible presence and distribution of life throughout the Universe. Such evidence would greatly stimulate the search for life (including intelligent forms) in the Universe.

The program to detect extra-solar planetary systems may be divided into terrestrial, Earth-orbital, and interstellar phases. The terrestrial program involves measurements of planetary-induced star motion by radial velocity shifts or by refined astrometric techniques. The Earth-orbital program would involve the use of a large space telescope designed to reveal planetary images in spite of the brightness of the star. It is possible to contemplate the construction of an interstellar spacecraft to visit nearby stars with planets in their life zones, and perhaps to search for life on such planets beyond the year 2000. Advanced propulsion systems are required because trip times are measured in decades.

Objective 125 – Can We Detect Extraterrestrial Intelligent Life?

It is now considered possible that intelligent life is widespread in the Universe. If a small fraction of such civilizations do achieve contact, it is possible that their own evolution would be furthered, and their longevity assured. Interstellar communication could be a phase of biological evolution.

Detection of probes, artifacts, or signals from other civilizations could be the most profound event in human history. Since many of them would undoubtedly be more advanced than ours, we might learn about achievements in science and technology that we cannot now imagine. We might learn also of the ways in which they have overcome the problems which beset us today. Such information would allow us to look into alternative futures for our own civilization, with the knowledge that certain courses of action have been successful elsewhere. The direct benefits to humanity could be considerable. In short, the promulgation of a program to detect extraterrestrial civilizations could gain us access to a galactic heritage of knowledge.

The questions of means of detecting extraterrestrial intelligent life is challenging. One concept envisages listening in the microwave region of the spectrum with a phased array of radiotelescopes. The technology is at hand, and the search could begin early in the 1980 to 2000 period, but the costs are high. Alternatives, such as laser communication or the detection of probes, could be examined. The location of the system should be determined. Alternative sites would be on the Earth, in Earth orbit, or on the Moon.

TECHNOLOGY REQUIREMENTS

Each of the 239 systems listed in Table 7 has been examined to determine the extent to which it depends upon advances in technology. The results of this examination are summarized in Appendix C and are discussed in detail in Reference 28.

We found, in general, that most systems require precursor programs of research and development; but that the extent of those requirements was within normal expectations for programs in a field that, by nature, is technologically demanding. It is appropriate, however, to note some areas which we feel require particular consideration:

- Many systems, both Earth-oriented and extraterrestrial, require that data from many sources be related in complex interactive models. Major advances will be required in modeling techniques, and in the models themselves, if highly complex undertakings, such as climate forecasting, are to be successful.
- Many Earth-oriented systems and a number of extraterrestrial systems depend upon significant advances in most of the elements of end-to-end data management.
- Although most of the systems considered could be effectively launched by the transportation systems expected to exist in the early 1980s, a number of the large space systems, such as those related to solar power collection, would require launch vehicles of greater capability or lower operational cost than any now under development. Other systems will require development of more capable in-orbit propulsion stages. These requirements are discussed in greater detail in Chapter 9.

- There is a general requirement for advance in most aspects of spacecraft design – stabilization, control, structural efficiency, electrical power, autonomy, environmental survivability, and communications.

In most of these examples, it can be expected that the needed technology advances will be made on a schedule that will support logical introduction of new system capability. Should events demand major steps in capability, the technology implications would, of course, have to be examined.

CHAPTER 6

THREE CHALLENGING OPPORTUNITIES

INTRODUCTION

Sixty-one objectives for future space activities were discussed in the previous chapter; all are considered important, and most are worthy of implementation during the next 20 to 25 years. Other important and exciting possibilities are discussed in Chapter 7. They are treated separately because of the size of the endeavors and because of questions in our minds relative to technical feasibility and/or timing.

Detailed implementation plans for any or all of the 61 objectives discussed in Chapter 5 should be prepared on the basis of priorities, relative need, available resources, and other factors. The systems summarized in Appendix B represent illustrative ways to pursue each objective and can be used for first-order program planning. The Study Group did not prepare an implementation plan for an overall space program, although three elements of a total program were examined in some detail.

In this chapter, plans for three possible elements of an overall program are discussed. They were prepared to illustrate the use of Appendix B and to illustrate other factors which emerged during the study. We also believe that these three examples deal with three important portions of a future space program, and can be used as starting points for the more detailed planning that is necessary prior to program implementation.

The three examples discussed in this chapter are:

Example A – To improve the understanding of the Earth's climate so that short- and long-term climatic changes can be predicted.

Example B – To substantially improve the understanding of the origin and evolution of the solar system.

Example C – To exploit the human presence in near-Earth orbit.

They illustrate the following:

Example A – The multiple use of Earth observation spacecraft for many objectives.

Example B – The importance of both reconnaissance of several bodies in the solar system and detailed studies of selected bodies.

Example C – The need for a manned space station for selected objectives, its importance for the long-term future of space, and its value in contributing to a broad range of objectives.

EXAMPLE A – CLIMATE

Background

There is clear evidence that the Earth's climate fluctuates over time periods of decades, centuries, and even longer. These changes affect a great many human activities. Much of the present world population depends on a complex, interdependent system by which food and fibre are efficiently grown where climate is favorable and then distributed around the world. The critical point is that the system is predicated upon a relatively constant climate; and changes in climate which may occur in just decades could impair the functioning of this system.

Climate as a potential space activity has been discussed under Objective 023 in Chapter 5 and related information is presented in Appendix B. It is discussed here in a programmatic manner, emphasizing the interrelations among space systems required to support the climate objective and their potential contribution to other objectives discussed in Chapter 5.

The general view is that the atmosphere has a memory of perhaps no more than a few months. This implies that conditions external to the atmosphere (e.g., the solar constant, Earth's orbital parameters and axial inclination, ocean currents, sea surface temperatures, ice and snow cover, land surface albedo, etc.) are the principal conditions determining climate. Their relative importance depends upon the time scales involved: Some (e.g., sea surface temperatures, ocean currents, ice and snow cover, land surface albedo) interact with the atmosphere in nonlinear feedback processes on time scales within which such interactions can take place. For any one time scale, there is a climate system with both internal and external conditions, both of which must be observed, analyzed, and represented in climate models. The external conditions serve as boundary conditions for the models, while the internal ones would be variables interacting with each other.

To understand climate, we must develop an observing system to monitor both the internal and external conditions affecting climate. The data must be globally distributed and much of it must be measured on a synoptic scale (500 km); some of it (e.g., ocean surface currents) must be observed with a spatial resolution (50 km) that is higher than is done presently. To meet the requirements for global distribution and the necessary spatial scales, the Earth-orbiting satellite is an excellent and, perhaps, essential viewing platform. Where *in-situ* measurements are necessary, Earth-orbiting satellites can play a role in collecting data from remote sites distributed around the globe.

The following outlines an approach to the understanding and prediction of climate and is presented in four areas: data base, environmental monitoring, model development and forecasting, and assessment of man-made activities:

DATA BASE – Develop a body of information on climate and its variation with enough statistical accuracy to distinguish actual climatic trends due to real climate *changes from normal weather fluctuations (climatic noise).* There are three sources of records:

- *Instrumental records* go back approximately 200 years, but only for the last 100 years has enough data been available about geographical climate patterns on a synoptic scale over significant portions of the globe.
- *Historical records* go back several thousand years and are particularly useful in assessing the social and economic impacts of climatic variability.
- *Paleoclimatic records* are relatively continuous for the past million years, and are especially useful from a quantitative standpoint for the past 100,000 years. Fragmentary records exist for up to hundreds of millions of years.

We suggest preparation of a worldwide inventory to determine the amount, nature, and location of past and present instrumental observations of the following variables: surface atmospheric pressure, temperature, and humidity; wind, rainfall, snowfall, and cloudiness; upper-air temperature, pressure-altitude profiles, wind, and humidity; ocean temperature, salinity, and currents; location and depth of land ice, sea ice, and snow; surface insulation, ground temperature, ground moisture, and runoff.

This inventory should identify the length of the observational record, the data quality, and the state of its availability. Selected data should be statistically analyzed to determine means, variances, covariances, and extremes for various periods of time, and four-dimensional analyses should be attempted to synthesize missing information. The presently available satellite data and, especially, the data to become available with the deployment of a climate monitoring system (discussed below), will be a very important part of extending the data base.

For the historical data, an organized effort should be made to locate, classify, and exploit new sources of recorded information on past variations of climate and, where possible, to relate this material to data from paleoclimatic sources.

The paleoclimatic data are derived from a wide variety of investigations including analysis of tree-ring growth patterns, glacier movements, lake and deep-sea sediments, ice cores, and studies of soil and periglacial stratigraphy. Data from tree rings, annually layered lake sediments, and some ice cores, are especially valuable for a climate program because they provide information for individual years; other sources provide more generalized climatic information on time scales of decades, centuries, and millennia. It is necessary to continue searching for such information in order to develop more accurate methods for dating, and to cross-check overlapping data sets.

MONITORING — Identify and monitor the factors that control and/or influence climate, determine the potential for change in each, and determine the climate's probable response to such changes. This activity involves monitoring both the climate system's internal parameters and the external factors affecting climate. A summary of the climatic variables or indices to be monitored are shown in Table 10 (page 66).

Satellites should be a basic part of the observing system. They are unique in their ability to make observations all over the globe with the same instrument. For some parameters, such as the solar radiation constant and the Earth radiation energy budget, Earth-orbiting satellites offer the only way of making the measurements with the required accuracy.

Another important part of the climate monitoring system is the deployment of *in-situ* sensors (e.g., floating and submerging ocean buoys, sea ice stations, etc.) for recording data that cannot be obtained by remote sensing from satellite orbit. The collection of data from *in-situ* sensors may be most efficiently done by means of relay through satellites.

The deployment of both satellite and *in-situ* sensors must be such that the resultant data are statistically valid. Certain parameters, such as the Earth radiation energy budget, cannot be continuously monitored at all points of the globe; therefore, a sampling strategy must be used that avoids bias and minimizes the statistical uncertainty of the results.

One critical feature that is required of many climate monitoring sensors is the ability to measure a variable over long periods (5 to 10 years) and to observe relatively small changes in it. This requires long-lived, highly stable instruments, and instrument-to-instrument comparisons to achieve continuity of data. Frequent, absolute calibration would be the best way to achieve continuity. We suggest that provision be made for periodic use of the Shuttle to perform absolute calibration of satellite instruments within the space environment. This capability will be available for polar orbiting satellites beginning in the early 1980s.

FORECASTING – Determine the predictability of climate on various time scales and, to the extent possible, develop a forecasting capability. Forecasting requires mathematical modeling of the climate system. The internal parameters of the climate system are those variables of the atmosphere, oceans, and land surface which interact to affect the climate. The external parameters are the variables (and constants) which affect but are not affected by climate. Which variables are internal and which are external depends upon the time scale over which the model will run. Sea surface temperature, for example, is always an internal parameter; but land surface albedo is an external parameter for seasonal and yearly time scales, and an internal parameter on time scales of a century or more.

The wide variety of climate models in use or undergoing development can be classified as follows:

- *Detailed Global Models* – in which the basic equations of fluid motion, radiative transfer, thermodynamic phase changes, and chemical and biochemical processes are applied to a climate system with four degrees of freedom (three space and one time); spatial resolution and time steps are selected so that the most important physical processes are explicity represented in the model; less important physical processes and subgrid phenomena are represented by empirical and/or statistical relationships.

- *Averaged Global Models* – in which one or more of the four degrees of freedom are averaged and their effects parameterized; models of this type often include substantial parameterization (based on empirical relationships derived from observations and/or numerical studies with detailed global models) of physical processes within the climate system.
- *Special Purpose Models* – in which only a limited portion of the climate system is modeled in order to examine in detail certain effects or feedback processes separately from the total climate system (e.g., a photochemical equilibrium model of the stratosphere).

All three model types are useful, and we envision the necessity of a hierarchy of models ranging from a fully detailed model to a highly averaged model. The validity of any one model will have a limited time span depending upon what physical processes are included in the model; or its validity may be bounded by certain constraints (e.g., barring changes in the ocean circulation or the land surface albedo, etc.).

HUMAN EFFECTS – Identify and monitor activities of humans which may change the climate, and assess their actual impact on the climate; investigate possible measures to counteract adverse changes or to bring about desirable changes. Humans, like other components of the biosphere, influence their environment. With the acceleration of technological growth, that influence may be an increasingly important factor in climate. The most direct impact of humans on the environment is the direct contamination of the atmosphere. In urban centers throughout the world, air pollution is becoming an acute problem. Even in places far removed from human activities it is possible to detect man-made contaminants in the air.

There are two types of air contamination: particulate and gaseous. While most particles remain in the troposphere and quickly settle or are washed out, some penetrate into the stratosphere where they may remain for years and possibly affect both the chemical balance of the stratosphere and the Earth radiation energy budget. Some gases injected into the atmosphere, such as methane and carbon monoxide, have plentiful natural sources and sink within the atmosphere, so that it is unlikely that humans have appreciably affected their steady-state concentrations. Other gases, such as carbon dioxide, are known to be increasing in concentration in the atmosphere (cf. Chapter 4), and the human contribution (from burning fuels) may be a major one. Still other gases, such as sulfur dioxide, photochemically react in the atmosphere to form particles (e.g., sulfates). In addition to its direct radiative effects, water vapor injected into the upper troposphere by jet aircraft may influence the amount and distribution of cirrus clouds, which have an appreciable effect on the Earth's radiation energy budget. Although it is fairly certain that humans have contaminated the air, little is known about its climatic impact.

Another part of the environment where humans have wrought changes with possible consequences for the Earth's climate is the land surface. Humans have reduced forests, eliminated swamps, built up urban centers and concrete roadways, and developed large arable areas for growing crops and raising cattle. These activities have had appreciable effects on climate over small regions; but an adequate assessment of the large-scale global effects is not available.

There may be certain feedback processes in the climate system which amplify the human alteration of the environment. Decreasing the plant cover over large areas (e.g., by overgrazing) increases the surface albedo, causing a net decrease in the absorption of solar energy. Such a decrease has been shown in one study to cause a decrease in rainfall, further reducing plant growth. A possible cause of droughts, therefore, may be related to overgrazing by domestic animals. Clearly, large arid regions such as the Sahara may have developed or have grown larger in some such fashion. For example, a thousand years ago the Negev Desert in Israel was populated with people who maintained an agricultural economy.

Key tools in monitoring and understanding the effects of civilization on the climate are observation systems and a variety of climate models which permit numerical analysis.

In addition to the activities summarized above, a complete understanding of climate phenomena may require collecting information that will increase the understanding of the interaction of solar activity with the Earth's atmosphere. Evidence is accumulating that the very small variations in received solar energy (as the sunspot cycle waxes and wanes) can affect the rainfall in agriculturally important regions. There is also evidence that the Earth may be approaching a new ice age. Can this be attributed to small variations in the energy received from the Sun? One component of the answer to these questions – an important one for predictions – is understanding the nature and cause of solar activity, and particularly why it varies (see the discussion of climate under Objective 103 in Chapter 5).

A Climate Program

It should be emphasized that an overall program for the understanding and prediction of climate will involve a wide variety of ground-based activities. Observations from space can be extremely useful and because of the nature of this study are stressed herein.

We expect that operational forecasting of climatic trends are feasible by the early to mid-1990s. This must be preceded by the development of predictive models and the monitoring (on a global basis) of the parameters listed in Table 10. A variety of ground and space systems have been identified in Chapter 5 which will permit the development and operation of a forecasting capability. Most of these systems were configured for objectives other than climate, but most of their observational data are required for climate. As will be noted later, the cost estimates as included in Appendix B for many of these systems is higher than if the systems were sized for climate only.

The elements of a climate program are listed in Table 17; the observations identified for "multiple objectives" are those which will provide data to objectives other than just climate. We have also included observations of the solar spectrum under "related objectives." These observations may not be vital for climate but we feel they will improve the long term understanding of climatic trends. The specific systems described in Appendix B for the modeling effort and to provide the observational data are included in Table 18.

Table 17

Climate Program Elements

OBJECTIVES SERVED ELEMENTS	PRIMARILY CLIMATE	MULTIPLE OBJECTIVES	RELATED OBJECTIVES
• OBSERVATIONS			
• EARTH RADIATION BUDGET	X		
• SURFACE RADIATION		X	
• ATMOSPHERIC GASES/PARTICLES		X	
• SNOW/SEA ICE		X	
• POLAR ICE SHEETS	X		
• HYDROLOGICAL PARAMETERS		X	
• OCEAN PRECIPITATION			
• SOIL MOISTURE			
• LAKE WATER			
• WATER RUNOFF			
• OCEAN PARAMETERS		X	
• SURFACE TEMPERATURE			
• UPPER LAYER HEAT CONTENT			
• WIND STRESS			
• SURFACE, CURRENTS, EDDIES			
• NEAR SURFACE CURRENTS			
• DEEP OCEAN CIRCULATION			
• SOLAR CONSTANT	X		
• SOLAR SPECTRUM			X
• MODELS			
• DETAILED GLOBAL MODELS	X		
• AVERAGED GLOBAL MODELS	X		
• SPECIAL PURPOSE MODELS	X		

A typical schedule for a climate program is illustrated in Figure 15. Only one example of the space observations required is included, in this case, Earth energy budget monitoring. Similar schedules have been developed for the other observational systems listed in Table 18. These data will be applied to the modeling activity illustrated in the bottom part of Figure 15.

The overall cost estimate for this example of a climate program is shown in Figure 16: The R&D cost of the basic climate systems illustrated in Tables 17 and 18

Table 18

Climate Program Systems

OBJECTIVES SERVED SYSTEMS	PRIMARILY CLIMATE	MULTIPLE OBJECTIVES	RELATED OBJECTIVES
• DEVELOPMENT SYSTEMS			
2017 – Earth Energy Budget Monitoring System	X		
2019 – Advanced Earth Energy Budget Monitoring System	X		
1076 – Solar Monitor	X		
3038 – Climate Parametric Systems Study	X		
3040 – Climate Forecasting System	X		
2001 – High Resolution Visible – IR System		X	
2003 – Very High Resolution Visible – IR System		X	
2007 – Long Wavelength Microwave System		X	
2009 – High Resolution Long Wavelength Microwave System		X	
2011 – Weather Survey System I		X	
2013 – Passive-Active Sensors, Large Scale Weather Survey System		X	
2015 – Multi-Frequency Active Sensor, Large Scale Weather Survey System		X	
2026 – Sea Survey Technology Satellite		X	
2027 – Sea Survey System		X	
2029 – High Resolution Sea Survey System		X	
3049 – Marine Parameter Experimental System		X	
4003 – Oceanographic Research		X	
2021 – Air Pollution Technology Satellite		X	
2022 – Stratospheric Monitoring System		X	
2024 – Stratospheric Constituents Monitoring System		X	
3042 – Stratospheric Parameter Experimental System		X	
4005 – Strato/Mesosphere Research		X	
2037 – Global Tropospheric Monitoring System		X	
2039 – Regional Tropospheric Monitoring System		X	
3060 – Tropospheric Parameter Experimental System		X	
1070 – 10,000 Kg Solar Observatories			X
1075 – Spacelab Solar Telescope Cluster			X
• OPERATIONAL SYSTEMS			
2018 – Earth Energy Budget Measuring System	X		
2020 – Advanced Earth Energy Budget Monitoring System	X		
3039 – Climate Parametric Systems Study	X		
3041 – Climate Forecasting System	X		
2002 – High Resolution Visible – IR System		X	
2004 – Very High Resolution Visible – IR System		X	
2008 – Long Wavelength Microwave System		X	
2010 – High Resolution Long Wavelength Microwave System		X	
2012 – Weather Survey System I		X	
2014 – Passive-Active Sensors, Large Scale Weather Survey System		X	
2016 – Multi-Frequency Active Sensor, Large Scale Weather Survey System		X	
2028 – Sea Survey System		X	
2030 – High Resolution Sea Survey System		X	
2023 – Stratospheric Monitoring System		X	
2025 – Stratospheric Constituents Monitoring System		X	
2038 – Global Tropospheric Monitoring System		X	
2040 – Regional Tropospheric Monitoring System		X	

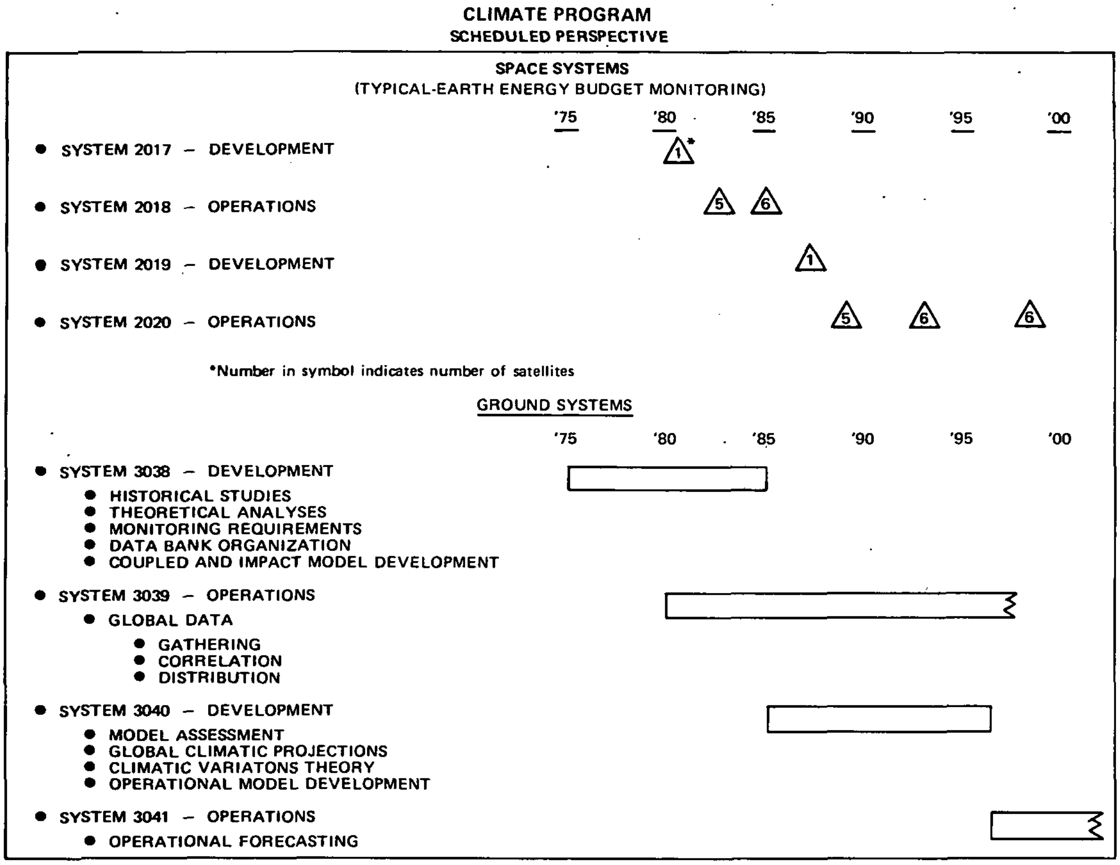

Figure 15. Climate Program Scheduled Perspective

would require an average of about 15 to 20 million dollars per year over the next 20 years. The R&D cost of the supporting systems is estimated to be an average of about 100 million dollars per year. If the supporting systems were reduced in scope to support only climate, we believe their costs would be about one-half (the dashed curves on the figure) of that shown in Appendix B. In summary, the research and development for a climate program would cost an average of between 50 and 60 million dollars per year for the next 25 years if all of the space systems were sized for only climate observations. This would increase by the amount shown in Figure 16 if the solar spectrum observations were included.

The operational costs of a climate program are also illustrated in Figure 16. We have again estimated that the cost of the supporting systems would be about one-half that shown in Appendix B if they were sized for only a climate program. Under this approach, the operational program for the prediction of climatic trends would average about 150 million dollars per year.

The supporting systems for the climate program also provide data for a number of other objectives; these are summarized in Table 19. While the space systems included

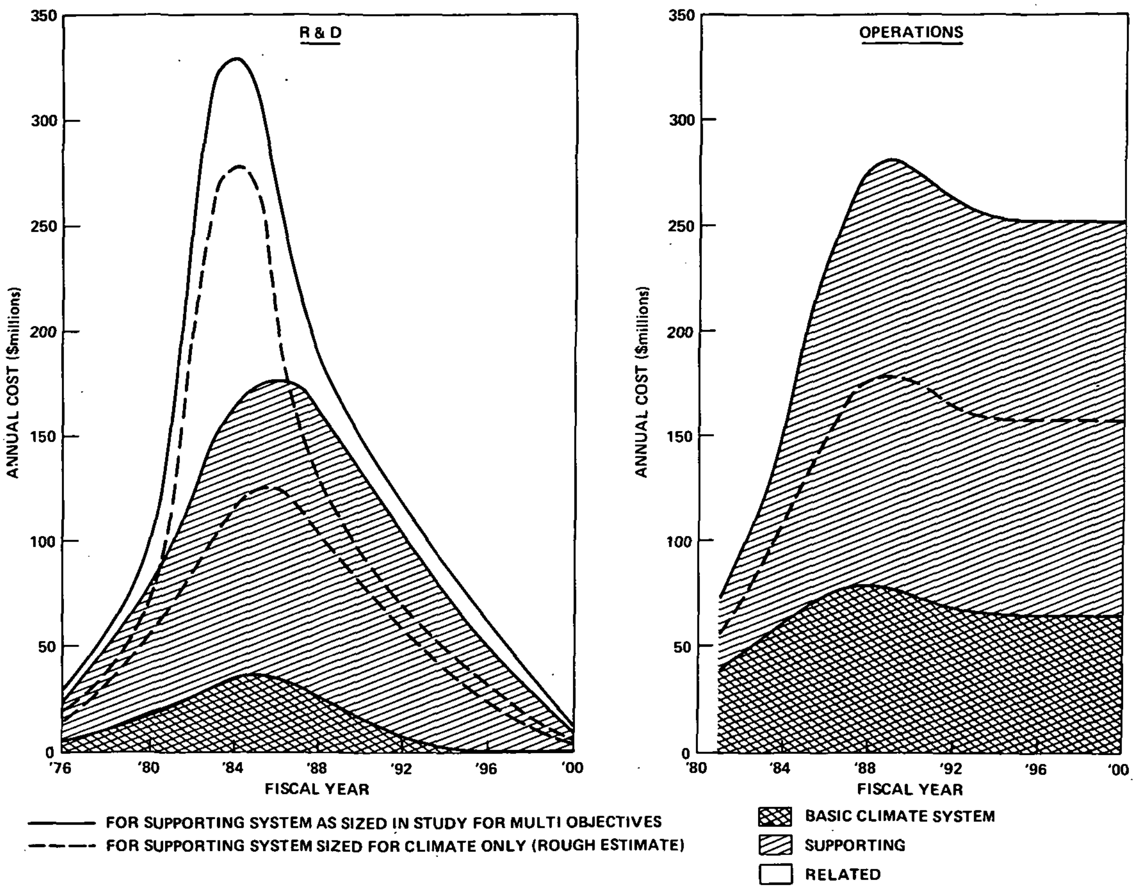

Figure 16. Climate Program Cost Estimate

Table 19

Other Objectives Served By Climate Program Support Systems

OBJECTIVE SERVED BY SUPPORTING SYSTEMS	AVERAGE ADDITIONAL ANNUAL COST*	OBJECTIVE SERVED BY SUPPORTING SYSTEMS	AVERAGE ADDITIONAL ANNUAL COST*
Land Use	$25 M	Insect Control	$5M
Crop Forecasting	16	Stratospheric Monitoring	5
Air Pollution	10	Living Marine Resources	5
Large Scale Weather	7	Geologic Mapping	4
Water Forecasting	7	Range Status	4
Marine Forecasting	5	Timber Inventory	3

*Cost unique to the additional objective served by the supporting systems costed as *Figure 16.*

in the climate program are required for these objectives, other activities unique to each objective are also required. The additional cost associated with these activities (technique development, analysis, modeling, and forecasting, etc.) are indicated.

Climate has a major impact on our society. The ability to predict, in advance, trends in the climate (whether they be by natural causes or by man-made effects) would provide society a better opportunity to cope with the future. We believe that the technology will be in hand in the near future to permit climate forecasting, and that observations from space will be a critical part in achieving this worthwhile objective. In addition, space observations for climate forecasting can also be applied to many other objectives.

EXAMPLE B – SOLAR SYSTEM

Background

This example deals with Theme 11, "Evolution of the Solar System," and the following objectives:

- What process occurred during formation of the solar system?
- How do planets, large satellites, and their atmospheres evolve?
- How can atmospheric dynamics be quantified?
- Origin and history of magnetic fields.

Note that objectives related to the origins and evolution of life in the solar system are dealt with in Theme 12 and are not included in this program example.

Two major goals are associated with a program of solar system studies: (1) to reconstruct the gross history of the planetary bodies from their formation about 5 billion years ago to the present, and (2) to gain insight on how an active planet like Earth functions – for example, what causes the reversals in the geomagnetic field, why are the ocean currents where they are, what parameters really determine climatic changes, etc.

In the last 15 years the Moon has been studied extensively, Mars to a lesser degree, and Venus, Mercury, and Jupiter to a limited degree. From the variety of information gained in these space missions, a new field in astronomy is beginning to emerge – the discipline of comparative planetology which aims at understanding the "life cycle" of an Earth-type planet. It is possible to do so, because we have learned that, although the planets were formed at approximately the same time, they are evolving at completely different rates because of their different sizes and locations in the solar system. By examining their present state we are, in effect, looking at what happens at different ages of a planet's existence. From these findings a story of the past and some deductions about the future of the Earth are beginning to be discussed in the scientific literature. Future planetary programs should be designed to test present theories about long-term planetary evolution, thereby increasing our confidence in deductions of trends in the changing conditions on the Earth's surface.

Comparative planetology is very much in its infancy. The planetary system is known to contain nine planets; 32 satellites – at least six comparable in size to the Moon and Mercury and two to the Earth; a great many asteroids; and a variety of comets. So far, we have only looked closely at the objects in our immediate neighborhood; yet more than 95% of the mass of the planetary system lies in Jupiter and beyond.

The question arises, What is the most logical way to study the objects in the solar system in order to bring the science of comparative planetology to maturity? We believe that the program should be built upon two different types of investigation:

1. The reconnaissance of the entire solar system, particularly of objects and regions about which little is known. Observations of many of the different bodies in the solar system are required in order to understand their differences and their similarities.
2. Intensive study of those objects which, after the first look, appear to be the scientifically most rewarding.

Included in the first category are close fly-by missions to comets, Saturn's rings, Uranus, Neptune, Pluto, the major satellites of the outer planets, and asteroids; and the mapping of the surface of Venus. The second category includes missions which perform detailed studies of the atmospheres and surfaces (with orbiters and probes) and which return samples of other planets to Earth for detailed investigation in ground-based laboratories. It is important that both activities be carried out simultaneously and at a steady pace, so that information from the reconnaissance of an object can serve as a basis for scientifically optimum detailed missions. An example of this strategy as it relates to a single planet is illustrated in Figure 17. Shown is the progression from the early Mariner fly-bys of Mars, to the current Viking missions, to the very important sample return missions, and eventually to manned exploration.

A Plan

Consistent with the rationale summarized above and what is now known about the various planetary bodies, we suggest the sequence of missions shown in Figure 18 for the period 1980 to 2000. This program assumes that the Viking missions in 1975/1976 will have been successful, that two Mariner spacecraft will have been launched in 1977 to Jupiter and Saturn, that a Pioneer Venus mission will have been successfully carried out in 1978, and that a reconnaissance type fly-by mission to Uranus will have been launched before 1980.

The purposes of the missions are:

- *Mercury:* Complete the reconnaissance with an orbiter in 1983 and proceed toward a sample return mission in the 1990s.
- *Venus:* An intensive study of the atmosphere of Venus will begin with the Pioneer Venus mission in 1978. This should be followed with an orbital radar

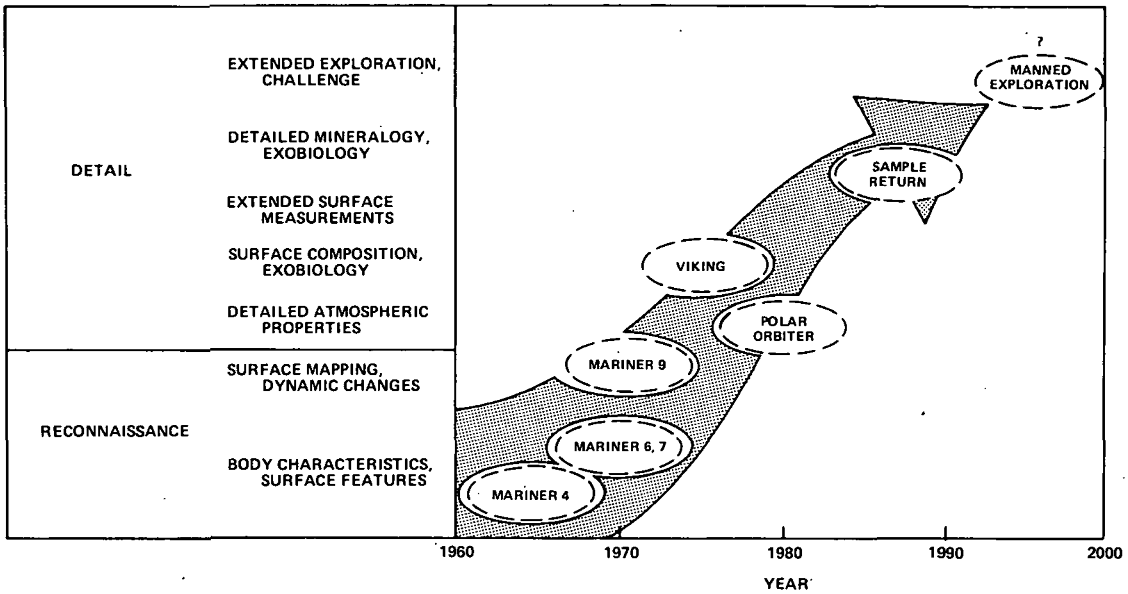

Figure 17. Evolution of Martian Exploration

mapper mission in the mid-1980s to "image" the planetary surface in detail. Surface lander and sample return missions would occur in the 1990s and early 2000s, respectively.

- *Moon:* Apollo samples have told us a great deal about the history of the lunar surface. However, many questions remain on the global structure and internal constitution of the Moon. A polar orbiter about the Moon in 1980 can clarify a number of these questions, and the same techniques can be anticipated for Mercury and Mars. Subsequent missions to the Moon should be based upon the orbiter results and further analysis of the Apollo data and samples.
- *Mars:* After Viking, it will be important to return a Martian sample to Earth so that detailed studies can be made as are now being conducted with lunar samples. Technically, an automated sample return mission to Mars appears feasible in the mid to late 1980s. Even though the complexity of the mission makes it very expensive (over 1.5 billion dollars), it has been included in Figure 18 because of its importance. Further planetary chemical reconnaissance is probably required to aid in the sample return mission; such a mission is shown in the mid 1980s.
- *Asteroids:* Reconnaissance of an asteroid by means of a rendezvous with a spacecraft should begin in the early 1990s.
- *Jupiter:* After Pioneers 10 and 11 and the two Mariners (assumed to be launched in 1977), we would be ready to start a detailed study of the Jovian System by an orbiter-atmospheric probe mission in the early 1980s. Many of

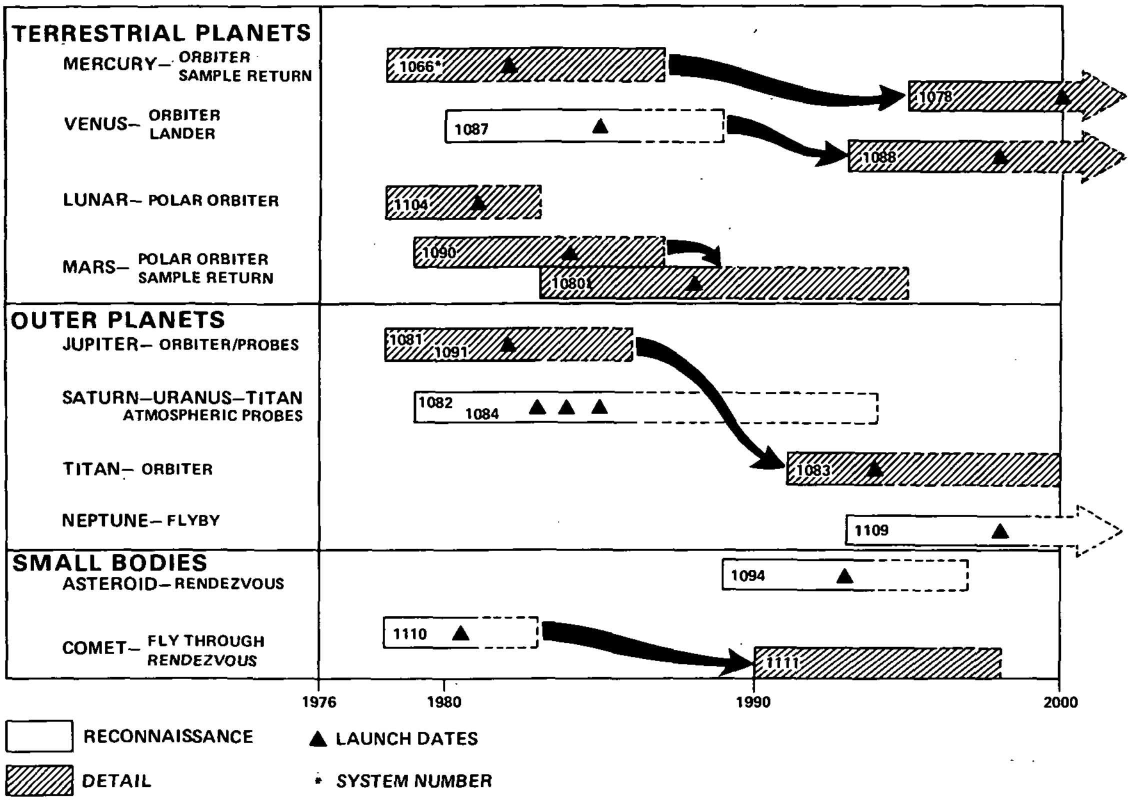

Figure 18. Solar System Program Schedule

the satellites of Jupiter may turn out to be scientifically very exciting. Other missions to Jupiter can only be defined after the results from the 1979 Mariner fly-bys are analyzed.

- *Saturn – Rings and Satellites:* Reconnaissance of Saturn will begin with the passage of Pioneer 11 in 1979 and continue with the Mariner fly-by in 1981. Probe missions into the Saturn and Titan atmospheres in the mid-1980s should answer first-order questions regarding the bulk structure of those atmospheres. A Titan orbiter could follow in the 1990s for the detailed study of the satellite, which at the moment appears to be at a very early stage of its evolution and may provide information on the early Earth.
- *Uranus:* In this sub-program, we assume that reconnaissance of the Uranian system will have been initiated before 1980. After this, a probe mission in the late 1980s appears appropriate in order to understand the major differences between the Uranian and Jovian planet/moon systems.
- *Neptune:* It is important that the exploration of Neptune begin in the near future; this planet will be difficult to study from Earth (even with large

telescopes in Earth orbit). We have assumed initial reconnaissance in the late 1990s.

- *Comets:* The reconnaissance of comets should begin with a first fly-through in the early 1980s, followed by a rendezvous mission in the 1990s.

Figure 19 shows the approximate annual cost for carrying out the program outlined above. The average funding is about 250 million dollars per year, with a major peak in the late 1980s because of the Mars surface sample return mission. A second funding buildup, in the mid-1990s, is due to the Mercury sample return mission and the Venus lander.

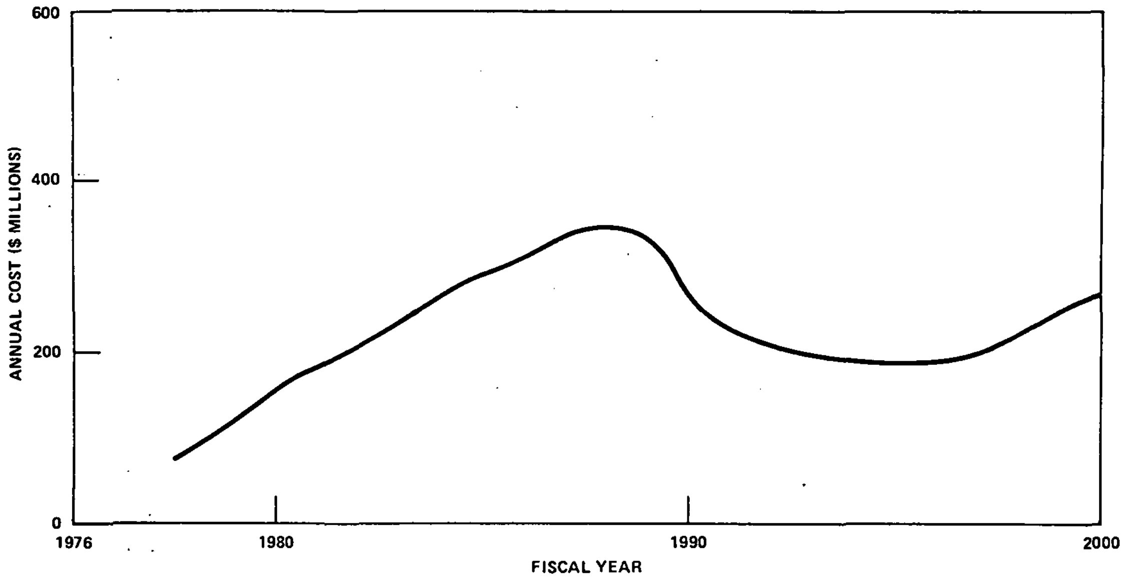

Figure 19. Solar System Program Cost Estimate

This program is paced at about the current level of activity for planetary exploration. If the funding level were reduced, we suggest slipping the schedule rather than deleting any particular mission. Deleting any one mission would require reexamination of the basic strategy. While it might be tempting to delete the sample return missions because of their high cost, lunar experience clearly shows the high scientific value of detailed sample analysis in Earth laboratories.

On the other hand, the program outlined above is not the most aggressive that could be envisioned. Because of the long trip times, reconnaissance and study of the outer planets could be accelerated only to a small degree, but missions such as comet and asteroid rendezvous, Mars orbiters, and Venus landers should be accelerated if additional resources were available.

EXAMPLE C – EXPLOITATION OF THE HUMAN PRESENCE IN NEAR-EARTH ORBIT

Background

A major element of the space program, since its inception in 1958, has been directed toward the effective use of the human presence in space. The first step, Project Mercury, showed that systems could be designed which would sustain human life in the space environment, and that a person, thus protected, could not only survive, but also could, at least for short periods, perform physical and mental functions much as he could on Earth. During the Mercury program, limited steps were taken in developing an understanding of some experimental activities to which a human could, by his presence, make a significant contribution.

The Gemini program extended beyond Mercury in three major areas. New steps in spacecraft systems design were made to accommodate the crew of two for periods up to 14 days as well as to provide the capability for rendezvous and docking, extravehicular activity, and an increased experimental program. Fuel cells for electrical power, rendezvous radar, a docking mechanism, more capable life-support system components, and a more extensive capability for crew control were among the advances introduced. Biomedical studies of the crews during the Gemini missions greatly increased confidence in our understanding of human abilities to function effectively in space for periods of at least 14 days. Finally, experiments conducted during the Gemini missions showed, even more conclusively than in Mercury, that for a range of space activities, from remote observation to spacecraft control, the human presence is required.

During Apollo, new steps were taken in spacecraft design and in studies contributing to understanding human physical and psychological reactions in space; but more importantly, more was learned about humans as explorers, experimentalists, and scientists in space.

The Skylab program dramatically proved the utility of humans as technicians and repairmen as they repaired their damaged spacecraft to permit an extensive experimental program, culminating in the 84-day Skylab mission 4. Medical experiments provided extensive data on their physical and physiological responses to missions of that duration. Physicists on Skylab, operating a cluster of solar telescopes, in conjunction with other scientists on the ground, showed the effectiveness of such a joint investigative team. Repeatedly, Skylab demonstrated the adaptability and versatility of the human in space supported by an analytical team on the ground.

The recent manned mission, Apollo-Soyuz, introduced a new dimension to the role of humans in orbit – that as an element of foreign policy.

The space program has consistently advanced in the development of manned systems, in understanding human contributions to space observations, and in the use of humans in a growing range of experimental tasks. The Shuttle/Spacelab combination will establish the next plateau of human utility in space by providing a laboratory environment with systems which can be economically returned to Earth, modified, re-equipped, and returned to space. The experimentalist will for the first time, have an opportunity to accompany his equipment into orbit, be present during the mission, and return to his ground laboratory with data and experimental specimens.

This program example capitalizes on the availability of Shuttle and Spacelab in performing the research and early operational phases of the objectives of Theme 06, use of the Environment of Space for Scientific and Commercial Purposes. It includes the development of a Space Station to provide the extended duration and greater capability needed for the long-term aspects of Theme 06, and it exploits the Space Station by including these long-term objectives.

A Plan

The key element of this program is the development and use of a permanent Space Station as the next step (Figure 20) in the exploitation of the human presence in space. The Space Station, which would be delivered into orbit and receive logistic support by the Shuttle, would provide total systems capability and mission duration that is complementary to that of the repetitively used Shuttle/Spacelab combination. As the objectives of Theme 06 illustrate, Spacelab would be used for research and development of investigations and processes exploiting the space environment. The Space Station would extend these activities in time and overall scope, where that extension is either required or enhances the effectiveness of the activity.

Use of the Spacelab and Space Station would not be reserved exclusively for activities in which human presence is an absolute requirement. Many objectives and systems discussed in Chapter 5 would be supported by the Spacelab and Space Station to increase their effectiveness or efficiency. Automated Earth-orbiting facilities, such as large astronomical telescopes, would rendezvous with the manned systems for maintenance, repair, update, and recalibration. Large structures such as antennas and solar energy systems would be assembled and evaluated by mechanics operating from the Spacelab or Space Station. Engineers would use the Spacelab and Space Station as an extension of their ground facilities to evaluate and qualify new components, systems, and instruments before they are used operationally.

In Chapter 7, we discuss a number of space activities which we believe will eventually occur, although we do not forecast a schedule on which they will take place. With the exception of interstellar flight, they depend on the information gained on systems and human performance during Space Station development and operation.

In our evaluation of the Space Station we also concluded that a highly visible permanent U.S. presence in space would represent a major contribution to evidence of our national prestige and vitality, as well as be a useful instrument of foreign policy (see Chapter 8).

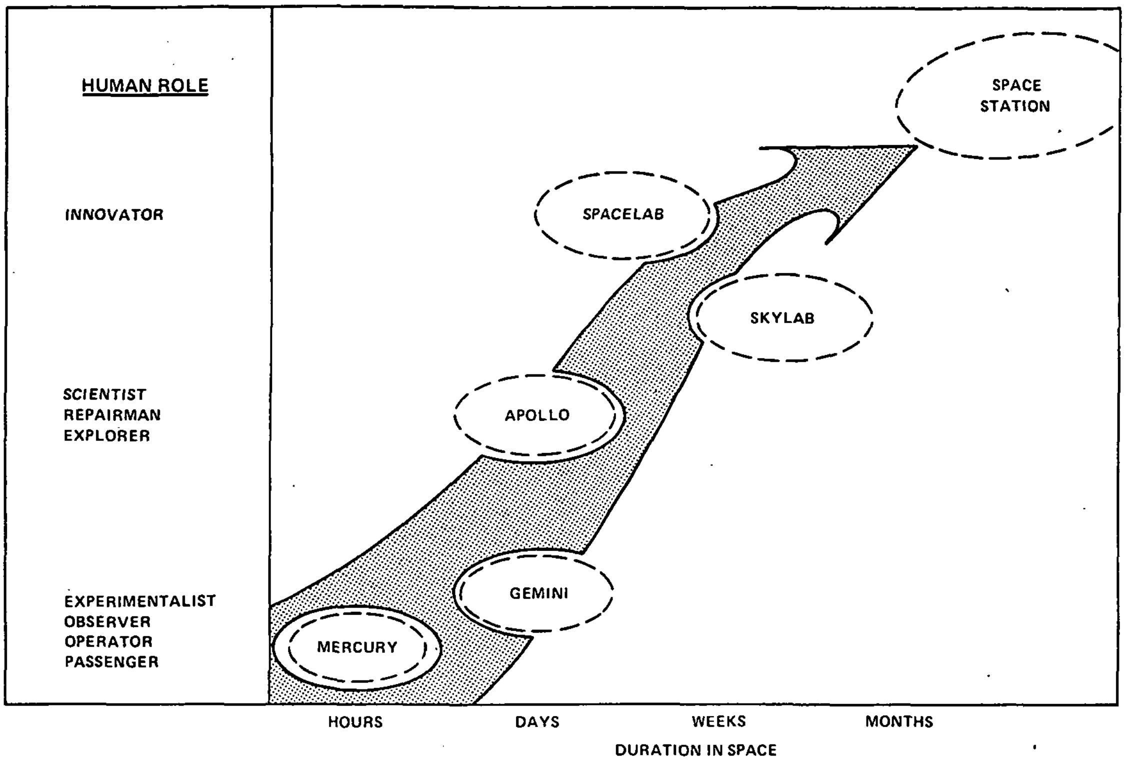

Figure 20. Evolution of the Role of the Human Presence in Space

The objectives included in this program are those in Theme 06, Use of the Environment of Space for Scientific and Commercial Purposes, and Objective 041, Solar Power Stations in Orbit. Theme 06 has seven objectives which range from support of commercial operations in space to basic research on disease processes. The activities associated with this program are illustrated in Figure 21. Six of the objectives would provide direct returns immediately. Living and Working in Space (Objective 066) is different. It is designed to prepare for future space opportunities. It is still not known how long humans can live safely and work effectively in space in full health. To state it differently: a number of questions remain about the total role which humans can ultimately carry out in space. Objective 066 is centered on answering this question. It thus forms the backbone of future human space activities and hence of many of the real opportunities to exploit space. It requires the completion of two of the following candidate space systems (see Appendix B): Human Performance in Space – Development (1037), and Human Performance in Space – Operational (1038). Only the latter system will answer the questions bearing on human ability to be personally involved in future planetary missions.

Commercial Processing (1032) and Biological Research (1034) are also major systems for this program. Both represent opportunities for economic gain from space.

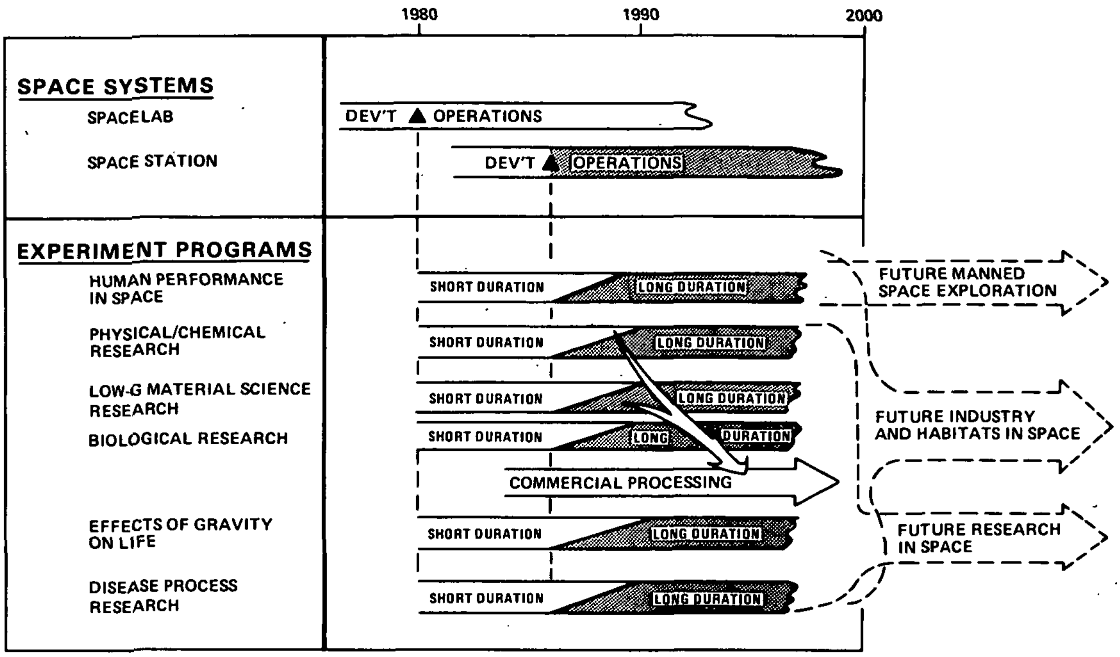

Figure 21. Exploiting the Human Presence in Low-Earth Orbit Program Schedule

Either may be wholly or partially funded by the private sector and each represents an attractive opportunity for exploitation of space by U.S. industry.

Both of the activities mentioned above require precursor systems: "Short-Term" Low-g Materials Science Research (1030) and "Short-Term" Biological Research (1033). These precursor systems might eventually evolve into more advanced research and development requiring semipermanent occupancy of space. This provides the basis of the systems "Long-Term" Low-g Materials Science and "Long-Term" Biological Research, both of these activities are aimed, like their predecessors, at advancing technology which would be applicable to commercial utilization of space.

Underlying all these activities are Systems 1029 and 1028, "Short-Term" and "Long-Term" Physical and Chemical Research. These systems provide basic physical and chemical laboratory experiments which require the unique space environment of Earth orbital flight: zero gravity and a vacuum essentially infinite in both extent and pumping speed. Experiments can be envisioned which have never been performed before, and would likely result in new branches of research in basic and applied physics and chemistry – which, in turn, may give rise to new commercial applications of space.

Two other systems, 1033 and 1034, would provide an opportunity for research to isolate and eliminate the effects of gravity from biological research experiments. These would provide a unique opportunity to learn about the manner in which gravity influences the existence and forms of life on Earth. This knowledge could also lead to an understanding of the forms extraterrestrial life might take.

Theme 04 includes Space Solar Power (Objective 041), which might ultimately provide a substantial portion of our terrestrial energy needs from space. This would be accomplished by collecting and converting solar energy in space to electric current, which is then transmitted to Earth via a microwave system where it is provided to our electrical power grid. The Solar Power Technology System (1007) provides experimentation on the Earth and in space to prove the basic technical feasibility of this concept. These space experiments can be conducted from Shuttle sorties.

The Solar Power Space Development Laboratory (1008) would verify the technical and economic viability of the actual processes and procedures necessary to accomplish large-scale provision of energy from space. This system would require the long-term presence of men in appropriate Space Station quarters and facilities to properly assemble, evaluate, and ultimately operate these energy systems.

Several of the systems required for this subprogram could be conducted in the Shuttle and/or Spacelab modules; however, this work would eventually require a permanent Space Station, which we have identified as System 1112. (A more complete description is given in Chapter 9.) To extend orbital occupancy time and allow long-term research and/or commercial processing, a permanent Space Station is a necessity.

The annual funding estimated for this program is shown in Figure 22; Table 20 illustrates five options. Each is progressively more inclusive, with Option "E" representing the program illustrated in Figures 21 and 22.

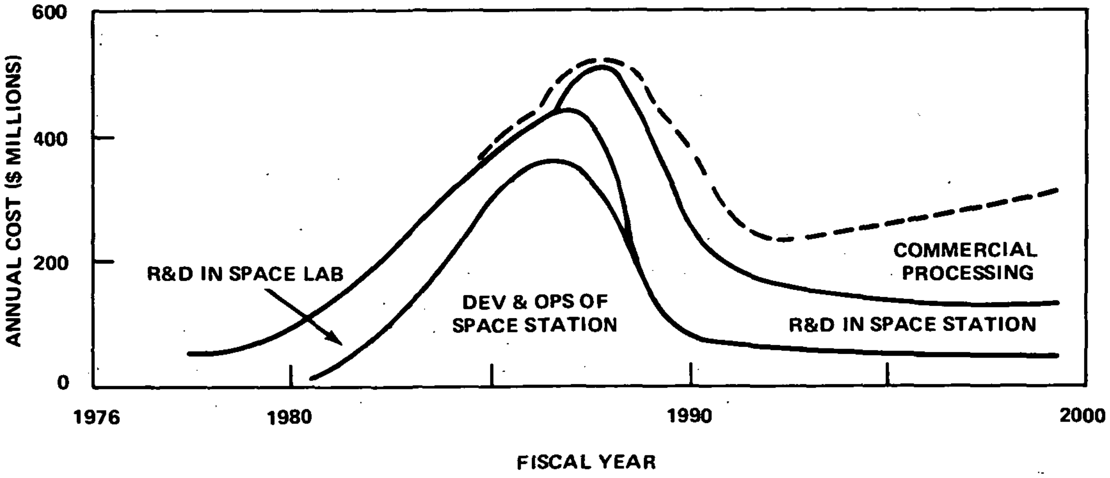

Figure 22. Exploiting the Human Presence in Low-Earth Orbit Estimated Cost

Table 20

Earth Orbit Subprogram Options and Cost Estimates

OPTION	SYSTEMS REQUIRED	SYSTEMS COST	COST
A	"SHORT-DURATION" PHYSICAL CHEMICAL RESEARCH "SHORT-DURATION" LOW-G MATERIAL SCIENCE RESEARCH "SHORT-DURATION" BIOLOGICAL RESEARCH PRELIMINARY EFFECTS OF GRAVITY ON LIFE HUMAN PERFORMANCE IN SPACE – DEVELOPMENT PRELIMINARY DISEASE PROCESSES RESEARCH	$ 160M 320 160 80 300 150	$1170M
B	*SPACE STATION 1A* HUMAN PERFORMANCE IN SPACE – OPERATIONAL	*$1750M* 590	$3510M
C	"LONG-DURATION" PHYSICAL CHEMICAL RESEARCH "LONG-DURATION" LOW-G MATERIAL SCIENCE RESEARCH "LONG-DURATION" BIOLOGICAL RESEARCH	$ 290M 590 290	$4680M
D	COMMERCIAL PROCESSING	$1000M	$5680M
E	EFFECTS OF GRAVITY ON LIFE DISEASE PROCESSES RESEARCH	$ 160M 310	$6150M

Option "A" is achieved with the use of only the Spacelab. The next level (Option "B") includes a Space Station and the system concerned with the operational aspects of human performance in space. The additional cost over Option "A" is the minimum required to begin to exploit space for long-term activities. Option "C" includes the long-term research efforts in physics, chemistry, low-g materials science, and biological materials. Commercial processing is then included in Option "D".

Option "E" represents major exploitation of the human presence in low-Earth orbit. The Space Station that is included would permit major research and provide a firm basis for the more advanced concepts discussed in the next chapter.

FINAL COMMENT

The plans discussed above are only illustrative. They do not represent – viewed either separately or collectively – a total space program, nor do they represent, necessarily, the optimum way to accomplish the stated objectives. They can, we believe, be a starting point for more detailed planning that is required. In addition, they illustrate:

- The multi-use of Earth Observation Spacecraft.
- The dual paths required for planetary exploration.
- The utility and desirability of a permanent Space Station in low-Earth orbit.

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CHAPTER 7

EXPLORING AND DEVELOPING THE SPACE FRONTIER

INTRODUCTION

In our lifetime we have seen the imaginative concepts of individual engineers become the serious design studies of groups of technologists. The results of these studies are based less and less on the "might be's" of the future and more and more on the proven technical accomplishments of the recent past. Now, suddenly and surprisingly, we realize the power of our new technology to carry out vast projects in space: colonize the Moon, construct huge stations in orbit, recover and process lunar minerals, send teams of explorers to the planets, and more. Some concepts, though sound in principle, are still far beyond our capabilities – such as a high-speed probe to another star or making another planet habitable. Yet we could initiate, with current technology, the design of a major lunar base or an orbiting factory housing thousands of workers for the construction of such things as satellite solar power stations. Still, it is unlikely that we would undertake such projects simply to demonstrate our technical prowess: such large expenditures would require an equally large measure of justification. The objectives to be satisfied by these major projects must be viewed, as were the other space objectives considered in this study, in terms of the degree to which they might satisfy human needs. The following are a few such future possibilities.

These projects might be discussed in terms of the Themes and Objectives of Chapter 5. For two reasons, however, we believe they merit separate consideration. The first reason is size. These projects are much larger than any previously discussed. Even the satellite power station of the objective on solar power would be embedded within a project to establish and operate a space industrial complex. The second reason is established need and timing. We are convinced that economic and social pressures present or clearly visible today could justify the R&D efforts necessary for the types of activities discussed in Chapters 5 and 6. For the types of projects discussed in this Chapter, however, we were not able to establish the social, political, and economic factors that would stimulate the investment of money and skill necessary for their accomplishment – even though, from a purely technical point of view, several of them might be realized before the turn of the century. Yet, we are convinced that most of the following possibilities will occur during our lifetime.

THE LUNAR BASE

The development of space would achieve economic justification more easily and rapidly if the resources necessary for such development could be gathered from space itself rather than having to be carried from Earth. This concept implies the development of the mineral resources of the Moon. A base on the Moon might well be considered a keystone for the development of space in the vicinity of Earth. This is not to say that such a base must precede other commercially-oriented space activities, but only that when a lunar mineral recovery capability is brought into being, it will greatly enhance the economic benefits to be derived from other activities. Furthermore, a lunar base could be used for a variety of scientific objectives.

In its initial form, a lunar base would be constructed almost completely of material brought from Earth, with unprocessed lunar material used perhaps as a protective cover over living quarters. The occupants would rely on resupply from Earth, at least for food requirements, although it might be possible to recycle much of the air and water (see, for example, References 29 and 30). Eventually, the base would become more self-sustaining. Lunar resources could provide materials for construction, soil for farms, and fuel for nuclear power reactors. As lunar base activities and their power requirements expanded, a nuclear power station would most likely be developed to utilize lunar thorium for conversion to U-233 in a breeder reactor. Once these steps had been taken to provide for base operations, the export of power to Earth orbit or to the Earth, via microwave or laser link, could be considered as a basis for expanding power generation on the Moon to multi-gigawatt power levels.

A high degree of self-sufficiency would be required for a cost-effective, viable base of operations. Present on the Moon are oxygen for life support and rocket propulsion; metals such as aluminum, magnesium, iron, and titanium for structural materials and rocket propulsion; the raw materials of ceramics and glasses for construction; silicon for photovoltaic devices; and thorium for nuclear breeder reactor fuels. The processing of lunar construction materials, such as melting rock into glass, would require considerable energy. Such energy is readily available by solar heating during the lunar days. Likewise, photovoltaics can provide electrical energy for chemical or thermal processing.

The need to minimize resupply from Earth implies a high degree of recycling of liquids, gases and solids. Although there have been studies of various physical-chemical techniques for this recycling, including the manufacture of artificial food, it seems much more realistic to take advantage of natural processes. Many design studies have considered the possibility of lunar agriculture, and indeed this approach seems reasonable. An early system probably would involve a combination of physical-chemical processing, plant growth (particularly food plants), and related soil bacteria to accomplish a recycling process. The need for resupply from Earth could be reduced to a small fraction of total requirements, for example certain nutrients, and perhaps hydrogen, to make up for unavoidable losses.

The short supply of hydrogen on the Moon may represent an important problem. Solar wind hydrogen is imbedded in the lunar surface soil, but the quantity is small. Even though there is ample oxygen in lunar minerals, this limited hydrogen supply will present a problem for the production of water and of high energy chemical rocket propellants. It may be that after a lunar base is firmly established, the most critical import from Earth will be hydrogen.

A considerable number of the activities at the first lunar base will undoubtedly be scientific in nature. This would involve both the exploration of the Moon and the use of its unique environment for other scientific experiments and observations. The far side of the Moon has often been suggested as an excellent site for major radio astronomy facilities, shielded from the radio noise produced by human activities on Earth. The structure could be quite large, since the gravity is low and there is no wind. The slow rotation rate of the Moon offers advantages both for radio and optical astronomy. Optical astronomy would have advantages similar to those found in free space – those due to the absence of the atmosphere. A lunar science base might also be useful in X-ray and cosmic-ray observations and as a site for detecting gravity waves.

In all these examples, there are obvious trade-offs between the lunar surface and an orbiting station. It would be premature at this point to assert which location would be best for which experiment. It is probably more realistic to say that advantages will be found in both.

The Moon offers a completely unique opportunity, however, for the development of mineral resources, and there are a number of reasons why such development might become commercially desirable. One such reason is the manufacture of satellite power stations. (The concept of satellite power stations in space is discussed in Chapter 5.) In view of the great demand for nonpolluting energy sources, we must assume this to be a viable candidate and examine its implications as it applies to the industrial development of the Moon.

Let us assume that: (1) through technological advances the installed cost of a power station in space will be reduced to that of its Earth-based competitors, 500 to 1,000 dollars per kilowatt (1975 dollars); and that (2) a significant fraction, perhaps all, of the annual increase in installed capacity will be represented by space systems by the year 2000. To put the concept in perspective, we must examine the magnitude of energy needs. If the demand for electricity continues as it has for the last 25 years, the demand for new installed capacity in the year 2000 will be between 150 and 200 million kilowatts in the U.S. for that year alone. At 500 dollars per kw, this implies an annual capital expenditure around the turn of the century of between 75 and 100 billion dollars, whatever the power source. This figure does not include the energy requirements of other nations (cf. Chapters 4 and 5).

Even if satellite power systems are economically competitive, including both the cost of the generators and the cost of launching them into orbit, a major fraction, perhaps one-half, of the cost of the system will be incurred by transporting the stations from Earth into geosynchronous orbit. Thus, the United States alone would be spending tens of billions of dollars a year to launch such stations into space.

If, however, substantial portions of the same stations could be built from lunar materials and launched from the Moon into geosynchronous orbit, the escape energy required would be only one-twentieth as much – a negligible fraction of the requirement of launchings from Earth. Thus, a lunar industry capable of manufacturing space power stations could be worth tens of billions of dollars a year. Could a lunar industrial base be capitalized and operated on such a budget? Certainly the idea is not unreasonable. It would represent a truly massive undertaking, much more demanding than the Apollo Project. It would require a work force of thousands of individuals on the Moon or in orbit, and probably require that living quarters be essentially fully recycling for all waste products and all food production, with little resupply from Earth.

Metals needed for manufacturing space power stations are apparently present in lunar minerals, but the mineral nature of lunar ores is different from those of the Earth (Reference 31). For example, the primary source of aluminum would probably be anorthosite, present in the lunar highlands, rather than bauxite, the usual source mineral on Earth. Iron and titanium are present in the form of ilmenite. Processing such ores would require different techniques than those we are familiar with. For example, many mineral recovery processes on Earth require water. At present, there is no evidence of any water on the Moon – just speculation as to the existence of ice pockets. It would be necessary to develop refining processes adapted to both lunar minerals and the lunar environment.

Another problem concerns the launching of structures from the Moon into free space. Although the energy requirements are small, rocket fuel would be hard to acquire. As we have noted, there is ample oxygen in lunar minerals, but no hydrogen. Perhaps embedded solar-wind hydrogen could be recovered and used as rocket fuel.

ORBITING INDUSTRY

A manufacturing facility, instead of being located on the Moon, could be a space station orbiting either the Moon or one of the Earth-Moon Lagrangian points (Reference 32). Operations on the Moon itself would be limited to mining and perhaps initial processing of ores. Standard-mass lumps of material would then be launched to the orbiting manufacturing facility not by rocket, but rather by a linear induction motor stretched over a track, several kilometers long, across the lunar surface. A solar, nuclear, or most likely a combination solar/nuclear generating plant on the lunar surface would provide the necessary power. Careful control of the direction and speed of the launcher would be essential to ensure that the payload would arrive at a small target near the manufacturing station, where it would be recovered automatically. Although the precision requirements are high, they seem to be achievable.

Under this arrangement, the major manufacturing organization would be at a space station, with most lunar operations carried out by automatic equipment requiring a comparatively small operation and maintenance crew.

The fractional gravity environment of the Moon may have deleterious medical effects, such as progressive loss of calcium from bone. An orbiting station would have the advantage that it could be rotated to provide any acceleration field required for the health of the crew and for any other special needs.

Launching finished products from such an orbiting manufacturing station is easier than launching such things from the Moon. High thrust is not required; solar electric propulsion, or even solar sailing, would suffice, if there were no demand for rapid flight times in the orbit-to-orbit transfer.

At present there would seem to be little economic justification for undertaking the development of a lunar mining and refining base for the purpose of returning metals to the Earth. However, developments might take place over the next few decades to change this. For example:

- A decrease in the cost of establishing and operating a lunar base, from, for example, low-cost heavy-lift launch vehicles.
- The discovery of rich mineral deposits on the Moon (our sample collection to date has been from a few isolated spots). The explorations have shown that the Moon is a differentiated body, and the existence of rich veins of ore is a possibility.
- The steady depletion of the Earth's ore deposits.

These considerations imply that the cost of mining pure-metal on the lunar surface and returning it to Earth will monotonically decrease with time, whereas the cost of refining the same metal from Earthly deposits will monotonically increase. Eventually, these two functions will cross. The exact time at which lunar mining becomes economically justifiable will depend on the particular metal in question.

It might well be argued that the time at which this occurs is to be measured in centuries rather than in decades, and that argument could not be disproved at present. However, we are running into difficulties with Earth's resources. Metal refining technology is not quite keeping up with the depletion of ore reserves, as is amply demonstrated by the steadily increasing prices of metals. Two metals which may be near the break-even point today are uranium and thorium. Even small quantities of these materials are of great value, and we already know that they are present in lunar minerals. Of course, it would take as much energy on the Moon to obtain these minerals (assuming the same concentrations in the ore) as it does on Earth. However, if energy were easier to obtain on the lunar surface (perhaps because of solar cells, made of lunar silicon, able to operate without the interference of an atmosphere), then it might well be profitable to refine uranium and thorium at a lunar base and launch it to the Earth.

To a large extent, the problem of mineral recovery is one of energy. With cheaper energy, poorer ores could be economically refined. Such cheap energy might become available from space power stations. Thus, one advance in space technology – space power stations – might postpone the utility of another – mining the Moon. At the same time, these two technologies support each other, since, as we have noted, it could be economically justifiable to mine the Moon for the production of space power stations. Recovering additional metals for return to industry in Earth orbit or on Earth would represent a rather small step beyond the activities necessary for space power station construction.

There are additional reasons for the development of industries in space and on the Moon other than the potential economic benefits. These reasons include:

- The advantage of weightlessness for research, processing, and manufacturing; and
- The use of space to minimize the polluting effects of our needs and aspirations on Earth.

With regard to pollution, many who contemplate the future advocate a massive move of industry into space for that reason alone.

It was noted in Chapter 5 that a half-degree change in the average temperature on the Earth has effects on food production in terms of billions of dollars. It has also been estimated that the energy consumption on the Earth necessary to provide all of the peoples of the world a degree of affluence approaching that of the U.S. could alter the Earth's average temperature by as much as 10 degrees. Such an alteration of the Earth's climate could result in irreparable and disastrous consequences to our biosphere. Even now, human needs and expectations are accelerating urgently, with incalculable effects on our biosphere.

Still, all peoples should be able to hope that their human condition will improve, that there might be means for them to achieve a standard of living more like that enjoyed by the average citizen of an industrialized nation. These pressures and their consequences could conceivably result in the relocation of a major portion of industry into space. Both the vacuum and the weightlessness in space will make it much easier to protect the space environment from industrial pollution than it now is to protect the Earth's environment.

PERMANENT HUMAN HABITATS IN SPACE

As we begin to work in space and remain there for longer periods, we will make the places we stay more pleasant and self-supporting. Eventually some of us will choose to remain in space. Beginning with early space stations and lunar bases, the eventual construction of space colonies would not be surprising.

The concept of creating colonies in space is currently receiving new attention. One approach (Reference 33) envisages large colonies consisting of pairs of cylinders, each cylinder 30 kilometers long by 6 kilometers in diameter. The cylinders would be counter-rotating at a rate to produce a one-g centrifugal acceleration on their inner surfaces. They would be linked together by tension and compression structures at the opposite ends forming an assembly with zero angular momentum. One end of the joined pair would be kept constantly pointed toward the sun. A cross section through a cylinder shows a hexagonal pattern, three opaque solid areas interspersed between three transparent segments. Outside the cylinders, large mirrors would reflect sunlight through a transparent area onto the opaque solid area diametrically opposite. The mirrors would move to recreate a 24-hour day-night cycle. Surrounding each cylinder would be a ring of smaller units for growing food. As presently conceived, such colonies could eventually each accommodate 10 million people, after a long development and construction cycle.

The early portion of this colony project, however, would start with much smaller units, similar in design, but with each cylinder being only 1 kilometer in length and 200 meters in radius. In these initial colonies (Figure 23), a work force of approximately 10,000 people would construct larger versions. Raw materials would come from the Moon, and the energy from sunlight. The Earth would supply some initial machinery, and all of the hydrogen required for water and industrial processing. Such colonies would be located in stable orbits near the Lagrangian points of the Earth-Moon system.

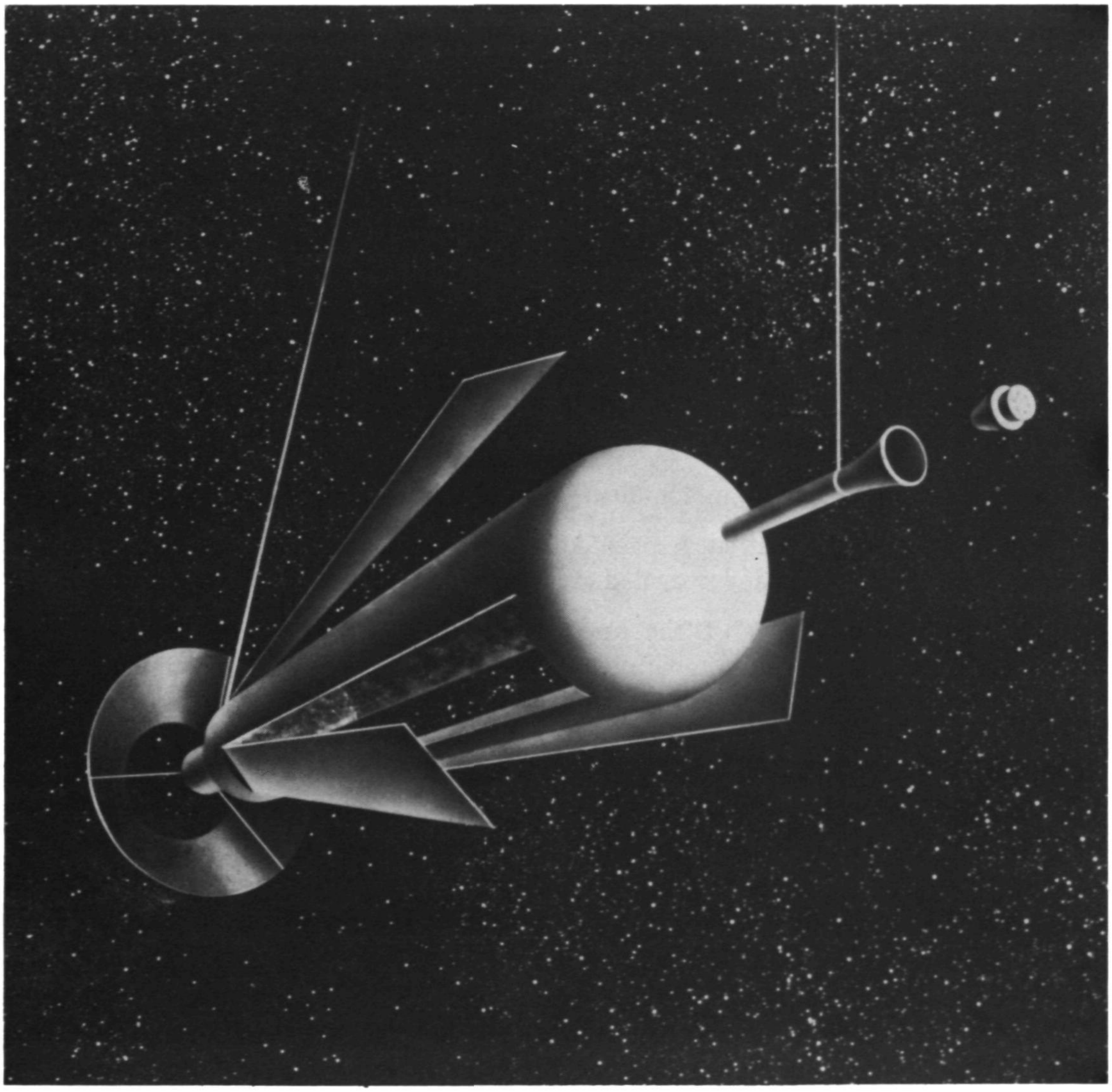

Figure 23. Early Model Space Colony (Courtesy of G. O'Neill)

Some individuals believe that during the 21st century, these colonies could help in relieving the Earth's population pressures, which even the most optimistic demographers believe will continue to be a problem for at least the next three generations (cf. Chapter 4).

Those who advocate this concept believe that the first small colony might be put into operation near the turn of the century. Many others discount the whole idea entirely, either on a feasibility basis, or as a sociological solution to Earth's population pressures. They do not believe that space colonization can possibly occur early enough or at a sufficient rate to mitigate the Earth's population problems.

The idea cannot, however, be discounted on purely technological grounds, although there are indeed major technological obstacles to the design concept described. As with many other potential applications of space technology, the decision to pursue such an objective would be based mainly on social, political, and economic factors. We do perceive a number of such factors interweaving in a manner that points toward the eventual colonization of space:

- The potential desirability and economic utility of space power stations
- The potential desirability of constructing such power stations from lunar material
- The desirability of carrying out the actual fabrication in an orbiting manufacturing facility rather than on the surface of the Moon
- The desirability of evolving such a manufacturing facility into a small, self-sustaining colony, both for its economic efficiency and for the well-being of its inhabitants
- The need to move more industry into space to preserve the Earth's biosphere
- The possibility that such space colonies might offer much more pleasant living conditions than many crowded areas of the Earth
- The human appeal of the opportunity to experiment with new social and political systems in comparatively small, independent, self-sustaining colonies, free of the pressures of an overcrowded Earth

COMMERCIAL SPACE TRANSPORTATION OF PEOPLE AND GOODS

The availability of heavy-lift, low-cost launch vehicles would open a new possibility for the commercial use of space – ordinary transportation. For somewhat the same cost as launch-to-low Earth orbit, the payload could be launched to any other place on the Earth, with a flight time of an hour or less. For some cargoes, this short flight time might justify the cost. By the turn of the century, recurring costs might come down to below 50 dollars per kilogram. As development proceeds, figures as low as 10 or 20 dollars per kilogram might be realized early in the next century. It would then be reasonable to think of such transport in terms of passengers with operational costs of 1,000 to 2,000 dollars each. The actual ticket would be more, since the transportation company would have not only operational costs, but also all of the other typical expenses, including amortizing the launch vehicle. For comparison, the cost of a one-way airline ticket from Los Angeles to Johannesburg today is 1,000 dollars.

We cannot ignore the possible eventual use of space travel for entertainment and recreation. Aeronautics advanced rapidly from its pioneering days, to Sunday afternoon pleasure flights, to today's extensive use of air travel for "jet-set" pleasure as well as commerce.

Just as communication through relay satellites is instrumental in the entertainment of people, so may be space transportation. Exotic tours today, such as extended "treks" through Africa, the Himalayas, or the Arctic regions, cost between 5,000 and 10,000 dollars. An advanced heavy-lift launch vehicle required for other needs could also place tourists in orbit for a reasonable stay at similar prices. In due course, a large number of people would take advantage of that possibility. One can extend the idea even further to the concept of a space hotel, accommodating vacationers for a one- to two-week stay in Earth orbit and eventually on the Moon.

These activities should be visualized as commercial enterprises, not requiring government financing. The U.S. Government might conceivably recoup a portion of its development costs by leasing or selling launch vehicles to commercial transportation companies. Additional costs necessary to design and develop adequate passenger accommodations would, of course, be borne by industry, if and when there was evidence that a profit could be made.

HUMAN EXPLORATION OF MARS, OTHER PLANETS, AND THEIR MOONS

The idea of human flight to and exploration of Mars has been discussed for many years. One of the principal arguments against it is the cost. But the costs may be significantly reduced when further advances are made in low-cost large-lift transportation. Such vehicles could place into Earth orbit the large spacecraft which would be required to sustain a crew over a lengthy mission. Such missions would also become more attractive if nuclear propulsion units were available which would decrease trip times to Mars, and even make possible the exploration of the asteroid belt and the moons of Jupiter within acceptable trip times. These flights are expected to occur once we learn how to remain in space for the long durations of such flights. Also, we recognize that detailed exploration of any planet in the solar system will require the presence of the human on the planet.

MINING THE ASTEROIDS

Many meteorites which strike the Earth consist almost entirely of a high-grade steel. It is likely that many asteroids have a similar composition, which presents an interesting possibility (Reference 34). An iron-nickel asteroid of reasonable size, for example, one kilometer in diameter, would represent four billion tons of high-quality steel with the value of about 400 billion dollars on the 1975 market. But, how does one return a four-billion-ton payload from the asteroid belt to the orbit of the Earth? One conceivable approach is the use of a high-thrust, high-specific-impulse propulsion device, perhaps using nuclear energy. It would then be necessary to cut up the object into manageable pieces which could be brought down safely through the atmosphere to a suitable location on the surface.

Mining the asteroids has the flavor of a purely 21st Century undertaking. First of all, the belt would have to be explored, since one would expect at best only a small fraction of the asteroids to have the proper mineral content. A suitable scheme would have to be developed, as would suitable techniques for carving up the object itself. The concept appears within the realm of feasibility, but in our opinion it is beyond 20th Century capabilities.

MAKING OTHER PLANETS AND MOONS HABITABLE

Our pioneering ancestors were fearful of the hostile environment of many desert areas that are now attractive resorts or productive gardens. Other regions of the Earth, such as lakes and streams, damaged by human activities, are being restored. Human beings, since building the first fire to keep warm, have altered the environment to make it more hospitable and more pleasant. As we explore and understand other environments there is every reason to expect that we will alter them, making them more benign to human and other life forms.

Many people have speculated about the possibility of modifying the atmospheres of the planets and the moons, specifically Mars, Venus, and the Earth's Moon. The initial problem is the creation of a breathable atmosphere. The situation is different in each of these three cases: the Moon has essentially no atmosphere, Mars has a very thin atmosphere of carbon dioxide, and Venus has a very dense atmosphere primarily of carbon dioxide, coupled with a hot surface at about 750°K.

Two modification techniques have received the most attention: Biological processes which would convert carbon dioxide into oxygen and some other carbon-containing molecule, and the direct application of energy by nuclear devices.

On Mars, for example, the explosion of a few nuclear devices might vaporize enough of the perennial northern cap to release enough carbon dioxide into the atmosphere to permanently increase the greenhouse effect. Thereafter, solar energy would evaporate the rest of the cap, producing a substantial rise in the density of the carbon dioxide atmosphere. The greenhouse effect would also lead to increased surface temperatures and support the growth of plants. If water and nitrogen could exist in Martian materials, or in the atmosphere, then such plants might gradually create a breathable oxygen atmosphere. But "gradually" is a long time; the process is limited by available sunlight. Even by covering the surface with highly efficient plants, we would still require hundreds of years to accomplish the result.

On Venus, huge amounts of carbon dioxide would have to be removed from the atmosphere to reduce the greenhouse effect enough to permit the surface to cool off.

The concept of seeding the atmosphere with a form of blue-green algae has been postulated, but conditions on the surface and in the atmosphere seem to be lethal to such organisms.

On the Moon, oxygen might be produced by heating lunar surface material with nuclear or solar thermal collection devices to release oxygen from the minerals. But the amount of energy required to produce a breathable atmosphere in this fashion is excessive. Furthermore, since the present vacuum condition might well prove extremely valuable for future lunar operations, there may be great advantages in maintaining the "atmosphere" of the Moon as it is now.

The general conclusion from these considerations is that although we can calculate how much energy would be required to modify the atmosphere of another planet, we have as yet no practical way of producing the energy needed to satisfy the truly huge requirements, nor of harnessing solar energy by biological processes efficiently enough to accomplish the objective in a reasonable amount of time.

INTERSTELLAR FLIGHT

A spacecraft launched by current propulsion technology would take thousands of years to reach the nearest star. It is likely that long before such a craft reached its target, our progeny here would have developed much more efficient propulsion techniques, and their craft would pass our early model enroute, making the whole mission somewhat pointless.

This progeny, however, might be close at hand, perhaps the next generation. It may be that before the turn of the century we will have developed nuclear rockets capable of cutting the flight time of a probe down to less than a century instead of a few thousand years (Reference 35). This may be attractive, but it is at least conceivable to do even better.

There are those who speculate on the possibility of creating and containing antimatter. This would indeed represent the most efficient energy storage system which we can conceive of permitting the total conversion of mass to energy. If such systems could actually be operated as rocket engines, the flight time to a star might be cut down to a matter of decades. However, we are not likely to see such engines before the year 2000. Although it is possible to create antimatter in high-energy accelerators, no one as yet has any idea of how to store it in such a way that it could be made available as an energy source for a rocket engine. What is required is not simply further development along an established line of research, but a completely new breakthrough or invention – and humans are notably unsuccessful at forecasting inventions.

If this new invention – the storing of antimatter – were to come along in the next decade, then it might be technically feasible to build an antimatter-reaction rocket motor by the turn of the century. However, this would be expensive in terms of energy. The minimum energy required to create antimatter is, of course, equal to the energy released in a matter-antimatter annihilation. However, the manufacture of antimatter particles is, in fact, a highly inefficient process, the total energy required being much higher than the energy eventually released; and energy will be costly for years to come.

Perhaps new breakthroughs will help to alleviate these problems. But, considering the technology which we can foresee as becoming available between now and the turn of the century, the notion of a flight to another star must remain, for the next two or three decades at least, an interesting but impractical speculation.

FINAL COMMENT

While the Study Group does not wish to suggest dates for realization of the concepts discussed above, we do believe that most of them will occur during our lifetime. We also wish to point out that in this study we did not speculate on the impact of major technological breakthroughs. Surely, many will occur and will have major impact on space activities and on their contributions to national needs.

CHAPTER 8

THE CONTRIBUTION OF POTENTIAL SPACE ACTIVITIES TO AREAS OF NATIONAL INTEREST

INTRODUCTION

One of the objectives of this study "to relate goals and objectives of civilian space activities to national goals and objectives" – suggested that the space activities discussed earlier in this report needed to be evaluated on the basis of national interest and benefit. However, nations and individuals characteristically have a wide range of interests and perceived needs, ranging from intellectual pursuits to physical well-being, from security to feelings of pride, etc. No single criterion exists for judging the candidates, just as no single definition of either the public interest or national goals exists. To deal with every notion of interest or benefit was impossible; thus, it became necessary for us to define a range of interests by considering various areas of national interest.

The areas we defined can also be viewed as categories of appeal. All persons who play a role in determining what our nation does are responsive in some degree to each of these areas of interest. The relative values that one individual would place on the separate areas would differ from those of another; each would, however, have an opinion as to the strength of contribution of an activity in each of the areas. It was our goal to estimate in the aggregate what those evaluations of the strength of contribution would be – not by any one interest group, but by American society as a whole. We do not allege that our evaluation corresponds to that of American society as a whole; rather, it is the opinion of the Study Group.

The objectives developed earlier in this report are responsive to a wide range of human needs. Some needs include exploration and the attainment of new knowledge. Those objectives responsive to physical needs can be considered as benefiting the individual U.S. citizen, as benefiting the nation as a body, or as benefiting the world as a whole. Each of these different perspectives suggests different criteria for evaluating the potential space objectives. It also seemed appropriate to evaluate each objective in terms of the degree to which achieving that objective would increase the prestige of our nation and the self esteem of individual citizens. And lastly, it seemed appropriate to evaluate each candidate objective in terms of the degree to which it could promote international cooperation.

We considered seven Areas of National Interest in order to provide a basis for the evaluation process. We believe these seven to be representative of the spectrum of interests held in this nation, and we view them as mutually exclusive. The areas used for this evaluation are:

1. *Expansion of Human Knowledge.* This area encompasses the acquisition of new knowledge; the expansion of human understanding about our place in the Universe and of physical, chemical, and biological processes; and the pursuit of answers to the major questions that our imagination leads us to ask. To rank high in this area, an objective would have to be perceived as making a significant advance in human knowledge in solving matters that have long puzzled humanity. Certainly any finding that influences our perception of our place and our uniqueness in the Universe would rate high in this area.

2. *Physical Benefits to Individual U.S. Citizens.* This area pertains to the material and social well-being of the individual U.S. citizen. It includes education of individuals, their economic posture, and the satisfaction of human needs in the areas of food, shelter, and security. To rate high in this area, an objective would have to be perceived by citizens as being relevant to their individual needs.

3. *Physical Benefits to Humanity on a Global Basis.* This area is similar to the previous area, except that it is broadened to include individuals around the world. It includes nutrition, education, health, world peace, and those elements that are fundamental to human existence. Space activities which are responsive to a common threat to the physical well-being of humanity and the perpetuation of the species would rate high in this category.

4. *Vitality (Strength) of the U.S. as a Nation.* This factor includes the well-being of the U.S. as a country and those factors which would increase the vitality and strength of the nation with relation to the world. Characteristics included are natural resources, the national economy, the national technology base, commerce and international trade, national security, and preservation of the democratic process. Space activities which would be in support of U.S. independence and leadership as a major world power would rate high in this area.

5. *National Prestige and Self-Esteem.* This area addresses the development of prestige and influence of the U.S. as a nation, as well as the enhancement of national self-esteem and the self-respect and national pride of U.S. citizens. Space activities which demonstrate the technological prowess and preeminence of the nation, and therefore support its form of government and its concepts, would rate high in this area. Major first accomplishments would also be highly ranked.

6. *Exploration of the Unknown.* This area addresses the appeal to those interests associated with the exploration of the unknown that have the characteristics of high adventure. For space activities, this would include "firsts" primarily by humans, but also by their machines in space, and implies "going there."

7. *International Cooperation and Understanding.* This area involves opportunities for international cooperative programs and a contribution to understanding among nations. Space activities which permit international cooperative efforts leading to improved relationships in the world community, and which would promote a more secure peace, would rate high in this area.

In an attempt to separate the individual judgments regarding the feasibility of achieving the objectives, each Study Group member evaluated the perceived contributions on the assumption that each objective was successfully achieved. From this evaluation, we determined the relative value of the various candidate space objectives. Those objectives that are predominant in their contribution, either to a single area or to a broad range of interests, were identified. Of course, the relative importance attached to each of these areas depends on the attitudes of individuals or groups, which are based on the conditions existing at the time. On a national scale, the relative importance of the seven areas is the aggregate of individual and group priorities. These priorities change with time and are influenced by current events and by perceived trends. A national space program based on these priorities is therefore not a static program, but rather should consider the long-range goals of the nation, and should be flexible enough to allow modifications in response to changing times and unforeseen occurrences.

The following discussion summarizes the concensus of the Study Group as to the strength of contribution of each candidate objective to each area of national interest, should that objective be pursued and achieved. We were able to evaluate the first four areas by considering the objectives without regard to the systems required to pursue them. Evaluation of the other three areas required consideration of the systems as well.

We fully recognize that everyone may not agree with our evaluations. However, the evaluation proved valuable to the Study Group and influenced our conclusions. We encourage others to perform a similar evaluation.

EVALUATION RESULTS*

Expansion of Human Knowledge

The extraordinary benefits accruing from the acquisition of knowledge are generally understood. Without science we would not have electric power, atomic power, computers, synthetic materials, antibiotics, high-yield agricultural systems, sophisticated means of transportation, worldwide communications, and many other technologies which aid the lives of human beings. Benefits such as these from science are not usually apparent until many years after the initial discovery. (Faraday was once asked by a special Commission of the British Parliament what possible use could ever result from his discoveries in the field of electricity and magnetism.) It is clear that serious political and cultural problems are with us, as always; but the needs of our emerging world civilization demand additional scientific understanding as the basis of future technologies. We cannot turn back. In the case of space science and exploration, we can only begin to imagine the future benefits to mankind of discoveries about our climate, the nature of black holes, of quasars and of gravity, and about primitive or intelligent life elsewhere in the Universe.

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*Only the objectives discussed in Chapter 5 were evaluated. We did not evaluate the activities described in Chapter 7 because of the uncertainties of timing of the activity.

Eight themes were considered to be capable of providing significant contributions to the expansion of human knowledge (see Table 21). Within these eight themes, seven objectives were rated highest:

Objective 023 – Climate Prediction
Objective 081 – How Did the Universe Begin?
Objective 083 – What are Quasars?
Objective 085 – What is the Nature of Gravity?
Objective 112 – How Do Planets, Large Satellites, and Their Atmospheres Evolve?
Objective 122 – Is There Extraterrestrial Life in the Solar System?
Objective 125 – Can We Detect Extraterrestrial Intelligent Life?

Table 21

Themes Providing Significant Contributions to Human Knowledge

THEME 02; PREDICTION AND PROTECTION OF THE ENVIRONMENT

021 – Large Scale Weather Forecasting
022 – Weather Modification Experiments Support
023 – Climate Prediction
024 – Stratospheric Changes and Effects
025 – Water Quality Monitoring
026 – Global Marine Weather Forecasting

THEME 06; USE OF ENVIRONMENT OF SPACE FOR SCIENTIFIC AND COMMERCIAL PURPOSES

061 – Basic Physics and Chemistry
062 – Materials Science
063 – Commercial Inorganic Processing
064 – Biological Materials Research and Applications
065 – Effects of Gravity on Terrestrial Life
066 – Living and Working in Space
067 – Physiology and Disease Processes

THEME 07; EARTH SCIENCE

071 – Earth's Magnetic Field
072 – Crustal Dynamics
073 – Ocean Interior and Dynamics
074 – Dynamics and Energetics of Lower Atmosphere
075 – Structure, Chemistry, Dynamics of Stratosphere/Mesosphere
076 – Ionosphere/Magnetosphere Coupling

THEME 08; THE NATURE OF THE UNIVERSE

081 – How Did the Universe Begin?
082 – How Do Galaxies Form and Evolve?
083 – What are Quasars?
084 – Will the Universe Expand Forever?
085 – What is the Nature of Gravity?

THEME 09; THE FATE OF MATTER

091 – Nature of Stellar Explosions
092 – Nature of Black Holes
093 – Where and How are Elements Formed?
094 – What is the Nature of Cosmic Rays?

THEME 10; THE LIFE CYCLE OF STARS

101 – Composition and Dynamics of Interstellar Matter
102 – Why and How Does Interstellar Dust Condense into Stars and Planets?
103 – Nature and Cause of Solar Activity?
104 – Corona and Interplanetary Plasma
105 – What is the Ultimate Fate of the Sun?

THEME 11; EVOLUTION OF THE SOLAR SYSTEM

111 – What Process Occurred During Formation of the Solar System?
112 – How do Planets, Large Satellites, and Their Atmospheres Evolve?
113 – How Can Atmospheric Dynamics be Quantified?
114 – Orgin and History of Magnetic Fields

THEME 12; ORIGINS AND FUTURE OF LIFE

121 – How did Life on Earth Originate?
122 – Is there Extraterrestrial Life in the Solar System?
123 – What Organic Chemistry Occurs in the Universe?
124 – Do Other Stars Have Planets?
125 – Can We Detect Extraterrestrial Intelligent Life?

Three of the objectives rated high in knowledge involve basic questions of physics and cosmology: How Did the Universe begin? What are Quasars? and What is the Nature of Gravity?

The origin of the Universe is a question to which the final answer will not be conclusively determined in the next 25 years, but significant progress is possible and we feel it would have considerable impact on public thinking. The Big Bang theory of the start of the Universe could probably be proved or disproved. If, in fact, the Big Bang theory is proved correct, the origin of some of the irregularities in the Universe, along with the position and movement of the observable Universe, might be determined.

"What are Quasars?" Astronomers have known for some time that quasars exist, but otherwise very little is known about them. They appear to be at very great distances from the Earth, emitting tremendous amounts of energy which modern physics is unable to explain. We felt that determining what this source of energy is would be perceived by the public as important. Increasing our understanding of gravity would also be regarded as a major accomplishment.

Objective 125 – "Can We Detect Extraterrestrial Intelligent Life?" could be stated: Are we alone? Are we the only civilization in the Universe? If not, can we be in communication with other civilizations? Where are they situated? What are they like? What is their science like? What is their society like? Indeed, it is possible that an interstellar communication network already exists, and that this network might have proved beneficial in the past and might be beneficial now for civilizations to exchange information with each other.

The detection of extraterrestrial intelligent life would have a profound influence on our perception of our place in the Universe. Any earthly society that is able to establish the existence of extraterrestrial intelligent life will have made one of the most important discoveries in history.

No less important than the detection of extraterrestrial intelligent life in the Universe is the search for extraterrestrial life of any form in the solar system. In the last ten years, several regions in the solar system have been identified where conditions may once have been like those on Earth: Mars, Jupiter, Saturn and one of Saturn's moons, Titan. Could life exist there? Are the general principles underlying the biological sciences constant in the same way that those in the physical sciences are, or could there be different biologies, different types of life structures than those on Earth? We know that organic molecules exist elsewhere than on the Earth. Is it possible that these molecules have combined into some form of life here in our solar system at other places than on the Earth?

The other two objectives which rated high deal with basic knowledge important to our own planet. The ability to predict climatic changes reliably, both in the short and the long term, could have an extremely important impact on food production and living conditions worldwide. However, the present state of knowledge regarding the climate is too limited to make such predictions possible. Climate cause-and-effect processes involve a multitude of complex interactions among parameters such as solar radiation, outgoing infrared radiation, ocean temperatures and heat flux, soil moisture, and atmospheric composition. The undertaking of this objective would help to provide insight into the links between these parameters. Clearly, the ability to understand and predict the climate is a challenge which will greatly contribute to fundamental human knowledge, as would an understanding of how the planets in our solar system evolved.

Physical Benefits to Individual U.S. Citizens, Physical Benefits to Humanity on a Global Basis, and Vitality (Strength) of the U.S. as a Nation

We concluded that the potential contributions of the space objectives to these three areas of national interest were very similar. Each of these areas was evaluated separately with different perspectives in mind. Only after the evaluation process did the similarities become evident.

As Table 22 shows, seven themes contribute strongly to these three areas, Theme 07, Earth Science, being necessary for the success of the other six. Within these seven themes, the following twelve objectives received high evaluation as to their strength of contribution to the composite of these three areas:

Objective 011 – Global Crop Production Forecasting
Objective 012 – Water Availability Forecasting
Objective 023 – Climate Prediction
Objective 024 – Stratospheric Changes and Effects
Objective 031 – Local Weather and Severe Storm Forecasting
Objective 033 – Hazard Forecasting from *In-Situ* Measurement
Objective 034 – Communication-Navigation Capability
Objective 041 – Solar Power Stations in Space
Objective 043 – Hazardous Waste Disposal in Space
Objective 051 – Domestic Communications
Objective 052 – Intercontinental Communications
Objective 062 – Materials Science

The importance of the food problem has been treated elsewhere in this report. The ability to perform global crop yield surveys rated high in the area of national vitality. Also, the ability to accurately predict food production around the world would be economically important to the United States. Such information could be used to help distribute food on a worldwide basis, or to assure that the U.S. is not manipulated into a disadvantageous economic bargaining position in relation to other countries.

The global crop yield prediction system clearly would have a significant impact on individuals around the world. Starvation and malnutrition already are common problems. A large portion of the world's food crop is lost every year because of poor distribution. The knowledge gained from a global crop yield prediction system will

Table 22

Themes Making Significant Contributions to: Physical Benefits to Individual U.S. Citizens; Physical Benefits to Humanity on a Global Basis; and Vitality of U.S. as a Nation

THEME 01; PRODUCTION AND MANAGEMENT OF FOOD AND FORESTRY RESOURCES

- 011 – Global Crop Production
- 012 – Water Availability Forecasting
- 013 – Land Use and Environmental Assessment
- 014 – Living Marine Resource Assessment
- 015 – Timber Inventory
- 016 – Rangeland Assessment

THEME 02; PREDICTION AND PROTECTION OF THE ENVIRONMENT

- 021 – Large Scale Weather Forecasting
- 022 – Weather Modification Experiments Support
- 023 – Climate Prediction
- 024 – Stratospheric Changes and Effects
- 025 – Water Quality Monitoring
- 026 – Global Marine Weather Forecasting

THEME 03; PROTECTION OF LIFE AND PROPERTY

- 031 – Local Weather and Severe Storm
- 032 – Tropospheric Pollutants Monitoring
- 033 – Hazard Forecasting from *In-Situ* Measurements
- 034 – Communication-Navigation
- 035 – Earthquake Prediction
- 036 – Control of Harmful Insects

THEME 04; ENERGY AND MINERAL EXPLORATION

- 041 – Solar Power Stations in Space
- 042 – Power Relay via Satellites
- 043 – Hazardous Waste Disposal in Space
- 044 – World Geologic Atlas

THEME 05; TRANSFER OF INFORMATION

- 051 – Domestic Communications
- 052 – Intercontinental Communications
- 053 – Personal Communications

THEME 06; USE OF ENVIRONMENT OF SPACE FOR SCIENTIFIC AND COMMERCIAL PURPOSES

- 061 – Basic Physics and Chemistry
- 062 – Materials Science
- 063 – Commercial Inorganic Processing
- 064 – Biological Materials Research and Applications
- 065 – Effects of Gravity on Terrestrial Life
- 066 – Living and Working in Space
- 067 – Physiology and Disease Processes

THEME 07; EARTH SCIENCE

- 071 – Earth's Magnetic Field
- 072 – Crustal Dynamics
- 073 – Ocean Interior and Dynamics
- 074 – Dynamics and Energetics of Lower Atmosphere
- 075 – Structure, Chemistry, and Dynamics of the Stratosphere/Mesosphere
- 076 – Ionosphere-Magnetosphere Coupling

help unplanned food production and will reduce losses by allowing the food distribution to be carefully planned in accordance with crop yields and human demands.

The water resources management system could be important from a national vitality standpoint, as it would enable the U.S. to more successfully manage one of its energy resources, to better plan water management for high crop yields, and to avert national disasters. All of these clearly have an economic impact. In addition, this system could be very valuable nationally as an export commodity sold on the international market and, as such, could affect our balance of trade.

We rated high the need to understand the climate and its variation better with the ultimate hope of being able to forecast this variation with a high level of confidence. The ability to predict a drought or exceptionally wet period one or two years into the future would be economically and socially very important to private individuals as well as to the nation and the world. The associated ability to accurately forecast the seasonal water availability was also highly rated. This activity would concentrate on those areas where most of the water originates from snow. Better estimates of the snowfall and of the snowpack would permit better estimates of the spring water runoff which, in turn, should improve the efficiency of water availability planning for crops, flood control, and hydroelectric power generation.

We felt that while a system of accurately predicting severe weather would not actually enable us to avoid all damage, it should permit the saving of many lives and reduce the cost impact of such events. Furthermore, a severe weather forecasting system would improve normal local weather forecasting, thus yielding additional benefits for local citizens.

The implementation of a worldwide space communication-navigation capability also was highly rated, since the world has a growing need to improve the navigation and position information available to ships and aircraft. The communication navigation system named above would permit collision avoidance procedures and search and rescue operations which would result in direct economic benefits to the U.S. Other less direct benefits would be derived from better navigation and communication information, enabling operators of ships and aircraft to run these more efficiently and, hence, more competitively on the world market. The communication navigation service should be attractive on the international market. Since the technological risk associated with developing and implementing this system is low and the economic returns are high, we felt that it was a system that could make a significant contribution.

The development of a space solar power system offers the potential for importing unlimited environmentally clean energy to the Earth. Clearly the ability of the nation to be energy-independent is sufficiently important to our country's strength and well-being that this becomes an important objective to pursue. Technically a space solar power system appears feasible; the primary question is whether it will be economically competitive, and only by undertaking the initial research and technology phases of the program can this be answered. This program could offer opportunity for international cooperation if it were deemed to be in the U.S. interest to involve other countries. Furthermore, if the system proves economically viable, the nation could export energy to other nations and, hence, improve our balance of payments.

There are two obvious ways to dispose of hazardous waste. One is to put it in a container and store it somewhere on the Earth, and the other is to put it in a container and launch it into space, out of our solar system. To do this would require a reasonably low-cost space transportation system and a convincingly high probability of safe disposal. The main advantage of a space disposal system is that once the waste is gone, it is gone. The primary question, that of safety, is a matter of developing adequately reliable launch vehicles and systems. The development of containers that can survive abortive reentry is technologically feasible. The growing worldwide need for a permanent hazardous waste disposal method makes this service important on a

U.S. and on a worldwide basis. A favorable economic position could develop for the nation providing the service.

We rated both the domestic communications and the international intercontinental communications objectives as being of major importance to the U.S. Both systems would allow the United States to retain its technological leadership in the international communications arena and would permit U.S. industry to be very competitive in the international marketplace. Consequently, achieving such objectives would enhance the United States' international trade position and balance of payments.

Exploration of the Unknown

We recognize the urge to explore as a fundamental characteristic of humanity, which includes the quest for new knowledge, but in a sense transcends it. This is an area in which space activities have already made significant contributions and can continue to do so. It is very likely that men have dreamed of journeying to the Moon and exploring the stars as long as they have lived on this planet.

Themes 08 through 12 (which also contribute to the expansion of knowledge) contribute to exploration, both in the nature of the objectives and in the means to pursue them. The specific objectives from within these themes which seem to us to offer a particular potential were:

Objective 122 – Is There Extraterrestrial Life in the Solar System?
Objective 125 – Can We Detect Extraterrestrial Intelligent Life?

We feel, however, that the greatest contribution to exploration comes from having human beings themselves serving as the explorers, and the further they go from Earth, the greater the contribution. We believe that humans will eventually undertake exploration of the solar system beyond the Moon. Our understanding of the trends in the immediate future do not indicate the social, economic and political factors that would stimulate such an undertaking before the turn of the century. Nevertheless, full satisfaction of the exploration urge requires, we believe, the presence of human beings.

National Prestige and Self-Esteem

Objectives which would make major contributions to this area would be characterized by their perceived significance. In this category, we felt that the greatest impact would result from major activities such as a permanent manned space station, or a lunar base, or the construction of a satellite power station.

It also seemed to us that scientific findings, perceived by the public as having deep significance would contribute to this area of interest. If data gathered from space were to contribute to a truly revolutionary discovery, that activity would certainly contribute to national prestige and the feelings of self-esteem of the U.S. citizen. We refer to a spectacular new scientific discovery with obvious public appeal and understanding, perhaps on a par with the Copernican Theory of the Solar System, Einstein's development of the Theory of Relativity, or the description of the structure of DNA. It is difficult to predict how and when scientific discoveries of this magnitude will be made, or to assert that space measurements will be involved. Yet we believe that within the objectives of Themes 07 through 12 there are opportunities for such discoveries; for example, the discovery of intelligent life in another solar system.

We also felt that activities which demonstrably alleviate widely perceived global needs would also be significant in this area of national interest. It is difficult to know which of the objectives in Themes 01 through 06 would meet this criterion. In addition to solar power, however, the accurate prediction of crop production around the globe would contribute significantly to national prestige.

International Cooperation

Many of the objectives cited by the Study Group would benefit from international cooperation. Indeed, some require it. However, this area of national interest has to do with the opportunities for cooperation and the following comments deal with our views on such opportunities.

We believe that there are opportunities for international cooperation in most of the objectives. This is true in Themes 07 through 12, because of their scientific nature. Science tends to be international in character and the United States has had, in the past, cooperative space science programs with other countries. We expect that there will be similar opportunities in the future.

We also expect that there are opportunities for international cooperation in many of the objectives contained in Themes 01 through 06. This is particularly true for objectives related to global needs (for example, global crop production). Some of our objectives were directed to national needs (for example, water availability) although other regions of the world could also benefit from such activities. Some (for example, the communications objectives) may involve competition between nations; in these objectives, therefore, cooperation between nations may be limited.

We concluded that the international space activities which generate the greatest public interest are those with people from various nations living and working together in space. Of the various systems considered, we felt that a permanent space station would be the best candidate, with a scientific lunar base a close second. The complex technical interfaces associated with joint missions to the planets caused us to consider such missions to be less attractive candidates for international cooperation.

SUMMARY

The evaluation summarized in this Chapter is one indication of the relationship between space activities and the national interest. Since the U.S. Space Program is largely a public program funded with public monies, it is important that others understand this relationship.

We were aided in our consideration of public attitudes toward space and national interest by the Hudson Institute study (Reference 36) and the survey conducted by Oklahoma State University (OSU) of high school and college students. The results of the OSU survey are summarized in Tables 23, 24, and 25.

Table 23

A Survey of the Attitudes of 15,000 Young People Toward Matters of Current National Importance*

1st Priority

- Controlling World Population
- Production and Distribution of Food
- Developing World Peace
- Discovering and Developing New Sources of Energy
- Controlling Inflation
- Protecting the Environment

2nd Priority

- Providing Job Opportunities for Everyone
- Developing the Potentials of the Oceans
- Maintaining the Quality of Life
- Land-Use Planning
- Finding Solutions for Social Problems
- Developing the Potentials of Space

3rd Priority

- Discovering New Mineral Deposits
- Developing Better Transportation and Communication Systems
- Expanding the Understanding of Humanity's Place in the Universe
- Controlling the Weather

*Items listed as First, Second, or Third Priority were so ranked by the largest percentage of students. The exact percentage depended upon the particular item ranked.

Table 24

A Survey of the Current Attitudes of 15,000 Young People Toward Space Priorities in the Next 10 to 20 Years*

1st Priority

- Explore and Monitor Earth Resources
- Develop International Understanding Through Cooperative Space Exploration
- Explore the Solar System and the Universe
- Defend our Nation
- Develop Space Stations to Manufacture Materials that Cannot be Made on Earth

2nd Priority

- Understand Weather Phenomena and Improve Long-Range Weather Predictions from Space
- Provide More and Better Communications
- Search for Intelligent Life Elsewhere in the Universe
- Establish a Lunar Base for Human Operations
- Study our Sun

3rd Priority

- Colonize the Moon
- Colonize Other Planets
- Modify Weather
- Send Human Crews to Mars

*Items listed as First, Second, or Third Priority were so ranked by the largest percentage of students. The exact percentage depended upon the particular item ranked.

Table 25

A Survey of the Current Attitudes of 15,000 Young People Toward the Importance of Past Space Accomplishments*

1st Importance

- Advancement of Scientific Knowledge
- Advancement of Technology
- Putting Men on the Moon
- Development of Communications Satellites

2nd Importance

- Development of Weather-Observing Satellites
- Development of Earth Resources Monitoring Systems in Space
- Providing Additional Jobs
- Development of International Understanding through Cooperative Space Exploraton

3rd Importance

- Exploration of the Planets
- Long-Duration Manned Flights in Skylab
- Development of Defense Satellites

*Items listed as First, Second, or Third Importance were so ranked by the largest percentage of students. The exact percentage depended upon the particular item ranked.

CHAPTER 9

IMPLICATIONS ON SPACE TRANSPORTATION, HUMAN FLIGHT, AND TECHNOLOGY

SPACE TRANSPORTATION

Present NASA planning for space transportation calls for the Space Shuttle, the Interim Upper Stage (IUS), and the Spacelab to be operational in 1980. A reusable upper stage, the Tug, is under consideration but is not planned for operational use earlier than 1985. These vehicles will gradually replace the expendable launch vehicles currently in use. Although the Outlook for Space Study did not evaluate the detailed performance characteristics of these vehicles, it did show that the Shuttle, IUS, and Spacelab would be extensively used in support of the objective and space systems considered, and that with few exceptions, the capabilities of the three vehicles will adequately meet the system requirements.

Exceptions to this general conclusion were in five categories. The first of these exceptions is the requirement for an advanced upper stage which is required by a number of the more demanding planetary systems. Systems 1085, Asteroid Sample Return; 1086, Comet Sample Return; 1092, Titan Lander; 1093, Uranus Orbiter; 1094, Asteroid Rendezvous; and 1111, Comet Rendezvous require such a stage. For these highly energetic missions, providing the necessary spacecraft velocities with all-chemical propulsion entails the use of many stages and attendant high vehicle gross liftoff weight. Introduction of a high specific impulse propulsive stage, using electric or magnetic means for rocket exhaust gas acceleration, coupled with nuclear energy or solar energy systems, can reduce gross liftoff weight, vehicle sizes, and number of stages. Such systems can achieve a net reduction in either, or both, system costs and system durations. A number of other planetary systems would benefit from the use of a high specific impulse stage, but could be accomplished with a combination of more conventional kick stages of the type currently in use. A solar electric propulsion system (SEP), or equivalent, with first use in about 1984 would support the indicated missions.

The second exception results from a number of systems such as 1114, Twelve Person Synchronous Space Station; 1115, Twelve Person Lunar Base; 1116, Crew Operated Flight to Mars; 1117, Industrial Space Facility; 1009, Solar Power Prototype Development; 1010, Solar Power Operational System; and 1012, Power Relay Prototype Development which require very large masses in Earth orbit. Although technically feasible through multiple Shuttle flights and orbital assembly, these systems would derive great benefit, and would, in a number of cases, justify the development of a system with considerably greater capability than that of the Shuttle. A new heavy-lift vehicle, capable of delivering payload weights of approximately 180,000 kilograms to low earth orbits could, by 1990, probably reduce costs of transportation to the order of $90 per kilogram. Further reductions in overall program costs for this type of system could be realized through the use of higher-performing upper stages for orbit-to-orbit transportation. These advanced stages would use advanced chemicals and nuclear and solar energy sources.

The third exception comes from systems with such high launch frequency that they would justify the development of a new or second generation launch system having extremely low recurring cost. In some respects this requirement is related to the requirement for a larger lift capability vehicle because reduction of launch cost is the major factor in each case. The minimum recurring cost vehicle requirement comes from Systems 1009, 1010, and 1012, the Power System series; 1015, Hazardous Waste Disposal; and 1117, Industrial Space Facility. A number of other systems with high traffic rate would obviously derive significant benefit from the use of a minimum recurring cost launch vehicle, although their utility is not dependent upon such a vehicle development.

The fourth exception is related to the limited manned capability, both duration and crew size, of the Shuttle/Spacelab combination. Systems 1029, Physical Chemical Research; 1031, Low-g Material Research; 1032, Commercial Inorganic Processing; 1034, Biological Isolation Production; 1036, Effect of Gravity on Life; 1040, Research Disease Processes; and 1112, 1113, and 1114, the Space Station Systems, require development of a Space Station. Many of the other systems can be accomplished more efficiently with a Space Station than with the Spacelab, but are not dependent on a new development.

The final exception comes from the systems which require personnel beyond the orbits which can be reached by the Shuttle. 1113, Space Station 2A and 1114, 12 Person Geosynch Space Station; 1115, Lunar Base; 1116, Man to Mars; and 1117, Industrial Space Facility, will require development of man-rated in-orbit propulsive vehicles and crew modules.

In general, all of these transportation systems, with the exception of the Space Station and electric propulsion vehicle, have operational requirements to begin no earlier than the 1990s; although these systems could come earlier if the proper factors were present to accelerate system development needs.

HUMAN PRESENCE AND OPERATIONS IN SPACE

Our consideration of the utility of humans in orbit began with an examination of past experience. The Mercury Program and the early Soviet manned program were aimed at developing the systems required to sustain life in space, and an understanding of the effect of space flight on human well-being and capabilities. They also formed an integral part of the high adventure inherent in human challenge of the unknown. The Gemini Program extended flight duration, provided experience in rendezvous and docking (which was to be an operational requirement of Apollo), and significantly extended the utility of the crew in their roles as technicians, experimenters and observers. The Apollo Program placed major demands on the crew for the operation of space systems, both in orbit and on the lunar surface: for the first time, crew members had a significant real-time voice in the conduct of experimental systems. It also introduced the effective combination of a scientific ground team in direct communication with astronauts, engaged in system planning and redirection based on crew observations and Earth-based analysis. This operational team concept was extended further in the Skylab Program in which a major portion of the success of the solar observation program was attributable to the skill of the onboard observers and the effective interaction between space crew and the ground team. The extended duration also permitted longer term study of the effects of weightlessness on humans. Perhaps the most significant crew function in the Skylab Program was their well-documented performance in overcoming the spacecraft difficulties which would otherwise have terminated the program at its outset. In the Apollo-Soyuz mission, the crew also performed significant experiments, but more importantly, men became diplomats in space. The presence of the two crews demonstrated an important aspect of foreign policy for both this country and the Soviet Union in a much more dramatic manner than an unmanned cooperative program could have done.

As we look at the objectives and systems projected for the period 1980 to 2000, our thinking is obviously based on an extrapolation of our past experience. This extrapolation is strongly influenced by the planning of the use of the Space Shuttle and Spacelab, both currently under development. Most of the operational systems considered in Themes 01 through 05 required precursor R&D programs to evaluate the utility of data from specific instruments and to verify the capability of planned operational instruments and subsystems. These R&D missions will rely heavily on crew presence in the Shuttle and Spacelab to adjust, modify and calibrate, as well as to retrieve free-flying systems and return to Earth.

Most of the activities in Theme 06 will require human operation of onboard equipment, and in some cases crew members themselves will be the subjects of experiments.

The extraterrestrial activities of Themes 08 through 12 will rely heavily on large orbital facilities where major instruments, with a wide range of attached sensors will be used in various configuration over an orbital lifetime of several years. These facilities, left to fly in an automated mode, would be periodically visited by a crew operated Shuttle for repair, update, recalibration, resupply of expendables, or, if required, for return to Earth and major overhaul. In addition, many instruments will undergo precursor qualification flight in a Shuttle before commitment to unattended flight – as was the case for systems directed to Themes 01 through 05.

A number of activities considered during the study will rely, even during system R&D, on assembly of major structures in space. Most significant of these is the program leading to a solar power station. The successful employment of these large-scale structures, delivered piece by piece into orbit, requires specialized work of assembly, alignment, testing and checkout. Crew members will become riggers and construction workers. Other systems in this class include large microwave systems, space antennas, and very large astronomical observatories.

Our considerations of system possibilities near and beyond the year 2000, as they are discussed in Chapter 7, focused on activities requiring crew involvement. In activities ranging from operation of equipment used to move lunar material for habitat construction to operation of precise facilities used to produce consumer goods in Earth orbit, crew members will be integral elements of the space systems far beyond the era of our study; this will be true of all the concepts we explored, except for automated interstellar missions.

Most of the manned activities we project for the next 10 to 20 years can be accomplished by the combined use of the Space Shuttle and the Spacelab. However, the Study Group, without exception, concluded that a small permanent Space Station for developing and extending human capabilities in space is the next logical requirement for proceeding along the continuum of space objectives. Although many of the objectives of Theme 06 can be accomplished in the Spacelab, their efficiency will be greatly enhanced by the long-term operations inherent in the Space Station. Studies of the effects of long duration space flight cannot be made in the Spacelab, which will be limited by the 30-day capability of the Shuttle. The development of an understanding of human capability to assemble large structures in space can begin with the Shuttle and Spacelab. A full understanding of such operations must, however, await a more permanent facility. In addition, the Space Station will free the Shuttle and Spacelab for the shorter missions to which they are more suited.

The basic characteristics of the initial Space Station considered in the study are shown in Figure 24. The station is delivered into low Earth orbit module by the Shuttle. Electrical energy is supplied by solar arrays deployed in orbit. The assembled spacecraft derives attitude stabilization from control moment gyros. Living and working quarters accommodate a crew of four or six with constant occupancy for the lifetime of the station. Initial crew stay-times would probably be three months. When assembled in orbit the basic station, made up of one module containing systems and accommodations required for basic habitability, one utilities module, and two laboratory modules, would weight approximately 100,000 pounds. The modular concept permits easy expansion in terms of more modules and is compatible with Shuttle delivery, resupply, and crew rotation.

In addition to its basic utility in support of the missions discussed in Chapter 5 and to the R&D necessary as precursor to the more advanced concepts of Chapter 7, we considered the Space Station to be a requirement to the acceptance of challenge offered by space and, perhaps most significantly of all, as an ideal program for effective and highly visible cooperative international ventures. For these reasons we included a permanent Space Station in our considerations of the program for the mid- to late-1980s.

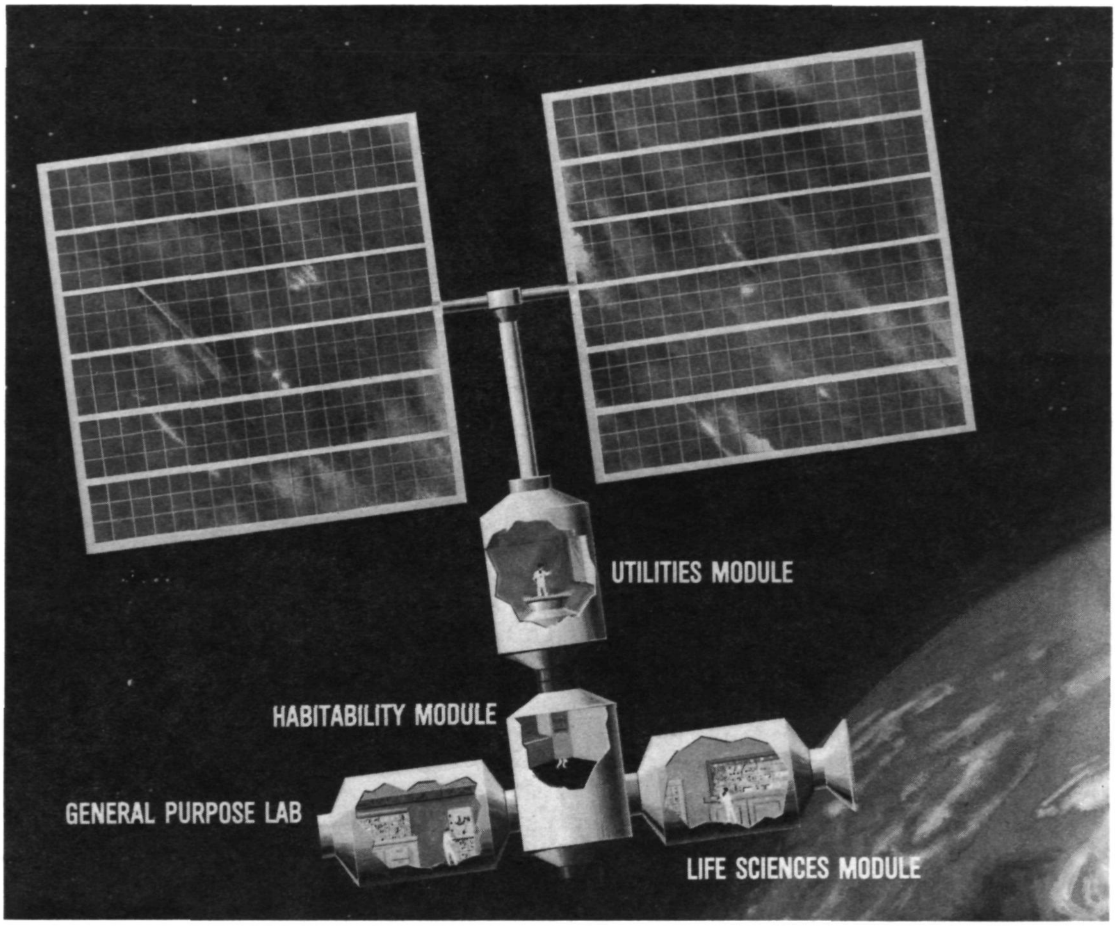


Figure 24. Initial 4-Man Space Station Concept

SPACE-RELATED TECHNOLOGY

The Prospects for Space Technology

In assessing the technology implications of the objectives of Chapters 5 and 7, it is appreciated that space-related technology is advanced only partially by the national space effort, with many advances coming from other sources in the U.S. and from other nations.

A *Forecast of Space Technology* was prepared and published as a reference volume to this report so that various objectives could be assessed with respect to technical feasibility. The various fields of technology that were investigated are described in some detail in Reference 28.

As the forecasting effort progressed we became increasingly aware of the following:

- *Civilization manifests itself through its ability to manage energy, provide* information, and shape matter to its needs. These three areas of management formed the basis for the forecasts.
- The advancement of technology achieves higher forms of such management, in that it uses the leverage of energy to communicate information more extensively and to shape matter to human needs.
- Technology and its advancement are a hallmark of developed nations, as being a means by which nations achieve their standard of living. Technological advancement is thus a fundamental requirement for nations aspiring to basic physical and intellectual satisfactions approaching those of developed nations.
- Technology is advanced by the sponsorship of government, through venture capital, and by the intellectual pursuits of academe.

The forecast determined that between now and the year 2000 a great number of advances will occur in the technologies applicable to space activities. These developments will make complex systems quite feasible and can significantly reduce the cost of accomplishments in space.

A selected set of six predicted technological advances described more completely in Reference 5 deserves special attention because each affects a broad spectrum of candidate objectives; because they represent particularly important examples from the various fields investigated; and because, as a group, they typify three different methods by which the advances will occur:

- By industry, largely without space agency and, in many instances, without any U.S. Government support.
- Partially by industry, but requiring a reasonable fraction of space agency or similar government support.
- Currently unique to space requirements and, therefore, relying almost totally on space agency support.

Those technologies which are being rapidly advanced by industry include new materials, advanced design techniques, data processing, some aspects of nonspace communications, and microelectronics. An important example in this first category where industry will push ahead is in the area of ultra-high-density microelectronics for the storage of information. Industry is not likely to advance the reliable use of microelectronics for space requirements, however:

1. Before the year 2000, ultra-high-density solid-state mass memory systems will be available, *capable of storing* 10^{14} *bits per cubic meter, an increase of* 10^6 beyond 1975 capabilities. This development will be the foundation for great advances in data management, and particularly in remote automatic information processing.

In the second category are advances which will occur to some extent in any case but which would benefit considerably by space agency support:

2. There will be major advances in automatic data processing, including data compression information extraction and pattern recognition. There could be major advances in automated (machine) intelligence, enabling spacecraft and surface rovers to conduct important tasks or sequences of operations under human direction, but without the need for constant step-by-step human control.
3. Nuclear devices, particularly fission reactors with various electrical energy converters, if developed for space applications, offer the best promise for low-weight and low-cost of all the energy storage systems deemed feasible between now and the year 2000. This forecast applies to the mass of the complete system required to store energy and make it available on demand in the form of electricity. Such stored energy could be used either for propulsion or station operation.
4. It is possible before the year 2000 to design, fabricate, deploy, and control large, lightweight structures in space, such as solar arrays, of the order of a square kilometer in area. For antennas, where pointing accuracies are more demanding, areas could be tens of thousands of square meters. Fabrication, deployment, and control capability will result primarily from space agency-sponsored developments. However, design capabilities and availability of important new structural materials will come, primarily, from industrial technological advances, many sponsored by governmental agencies other than NASA.

Examples of those technologies in the third category which rely almost completely on space agency support for their advancement include propulsion, space navigation, and life support systems. The technology necessary to the reliability and extremely long life of systems in the unique environment of space will require strong space agency support because of that environment. Only through extending the life of space systems will the costs of some candidate space activities reach the approval level.

5. It has been forecast that it could be possible by the year 2000 to provide nearly fully closed (recycling) biological life support systems for large crews in space or on the Moon, with reliable lifetimes of several years and with "farm" areas of the order of 100 square meters per capita. Very little advance has occurred in this area to date, however.
6. It could be possible in the time period in question to develop reusable, vertical landing (perhaps in water), heavy-lift vehicles for low-cost Earth-to-orbit transportation. Such vehicles could be capable of delivering payloads of a few hundred thousand kilograms to low-Earth orbit at a cost of 50 dollars per kilogram, or less.

Some of the forecasts presented in Reference 28 are based on the assumption that certain breakthroughs will take place, although exactly what those breakthroughs are likely to be is unknown at present. For example, the speed of information processing depends fundamentally on the limit of the velocity of light. For some of the projected increases in computer processing speeds to be realized, there will have to be significant advances in the architecture of large machines employing parallel rather than serial or sequential processing techniques. Exactly how this will be accomplished, especially for very large processor arrays (>1000), is uncertain, but the forecasters are confident that it will be accomplished.

There are other areas in which the necessary breakthroughs do not seem so likely, at least before the turn of the century. An example of this is the technology which would enable spacecraft to be sent out from the solar system toward some other star with reasonable times of flight – say, less than 50 years. One might speculate on how this might be accomplished using such things as lightweight nuclear fusion microexplosion rockets, gas core nuclear fission rockets, or even the production and storage of antimatter. Certainly, propulsion systems available today or in the near future are incapable of meeting interstellar mission objectives and are not forecast to be available before the year 2000.

Reference 28 is organized into the fields of Information, Energy, and Matter as shown in Table 26 and the following three sections address some of the specific findings in these three fields.

The Management of Information

Overview

The next 25 years will see a steady and rapid growth in the amount of data collected in space and returned to the Earth, combined with the necessity to acquire, process, and disseminate this information at low cost. These two factors will be the stimuli for the technological evolution of space-related information systems. As the industry advances, space communications systems will benefit from both increased capabilities and decreased costs of digital hardware and high-rate ground communication facilities.

Greater autonomy will be given to remote systems as a result of these technological advances, particularly the capabilities of space-borne information hardware and application software. This will result in more efficient use of Earth-based control and communication facilities.

Increased understanding of information functions will result in more emphasis on end-to-end information system design. Improved systems design approaches will take better advantage of the technology becoming available, and will minimize the overall costs of information management. At the same time, these design approaches will place increasing demands on software capabilities, which may not advance as rapidly as hardware capabilities and may become even more a limiting factor than they are in 1975.

Table 26

Content of Technological Fields Used for "A Forecast of Space Technology, 1980-2000"

	Information	Energy	Matter
Acquiring	• Instruments (1) Electromagnetic waves (2) Particles (3) Chemical properties (4) Physical properties (5) *Biological properties* • Apparatus	• Photons • Magnetic flux • *Indigenous materials*	• Animate (1) Space medicine (2) Plants in space (3) Space processing (4) Contaminants • Inanimate (1) Microstructures (microelectronics) (2) Macrostructures (materials and structures) (a) On Earth (b) In space (c) On the Moon (mining)
Processing	• Instruction and use of machines • Design and construction of machines • Automation of cognition	• Conversion of stored energy to (1) Electrical energy (2) Kinetic energy for propulsion (a) Earth-to-orbit (b) Space	
Transferring	• Electromagnetic links (1) Spaceborne devices (2) Ground-based devices (3) Near-Earth systems (4) Deep space systems • Other links (1) *Acoustic*	• Beamed photons (1) Laser (2) Microwave	• Path planning • Object location • Translation/orientation control (1) Through space (2) Through atmospheres (3) *On solid surfaces*
Storing	• Storage systems (1) Magnetic (2) Electro-optical (3) Solid-state	• Mechanical • Thermal • Electronic (chemical) • Nuclear • Magnetic • Antimatter	• Maintenance of state (survival) (1) Life support systems (2) Containment of pressurized fluid (3) Meteoroid protection (4) Radiation protection (5) Temperature control

The trend most likely to influence developments in information management is the rapid growth in the quantities of data which will be gathered from systems in space. By the year 2000, imaging devices on Earth-oriented spacecraft will be able to return a thousand times more data than in 1975. In non-imaging experiments, increasing quantities of data will result from increases in both sensitivity (by a factor of 30 to 3,000) and in the range and versatility of remote sensing instruments. Thus, it will be necessary to provide for the handling of a much greater influx of data from both Earth-orbiting and remote spacecraft, as well as to be more selective in transmitting the data from the source.

The search for those solutions will place greater emphasis on designing the entire information system from end-to-end for a given application. While studies of this kind are conducted now, our ability to make use of their results is limited by lack of capabilities in the following areas:

1. High cost of meeting reliability requirements for complex flight data systems
2. Limitations in data compression and other information extraction algorithms
3. Insufficient capacity of space-to-Earth communication links for some systems such as those in deep space
4. The requirement for step-by-step human control of complex instruments and other systems used for remote tasks
5. Complex software systems whose generation is often slow and costly, and whose use often demands the user be a computer hardware and software expert to avoid being isolated from the data.

Technology Forecasts in the Field of Information

We expect that significant advances will be made in the following areas, leading toward more efficient and economical information management systems.

Computer Hardware – The rapid development of large-scale-integrated (LSI) circuit technology and its diminishing costs will continue to impact all aspects of information management, but especially the areas of processing and storing. The single-chip processors being introduced today will expand the number of computers and the computing power available at an expected rate of three to four orders of magnitude per decade. This increase will be reflected largely in growing use of small dedicated computers rather than medium-to-large-scale systems. The performance capability of these larger computers is expected to grow at the rate of one order of magnitude per decade over the next 25 years rather than at the two-orders-per-decade rate of the past 20 years. The increase will come primarily from advances in parallel processing and intelligent peripherals. Users with limited computing facilities will have access to large-scale systems through federated computer system networks, currently in the development stage. The storage capacity of space-borne and Earth-based systems is forecast as shown in Figure 25.

Communication – It is expected that communication links between Earth and both Earth-orbiting satellites and planetary spacecraft will increase in capacity to accommodate data handling requirements, and the cost of these links will decrease. Almost all deep-space links, and a majority of Earth-satellite links will continue to use microwave bands up to 30 GHz. Higher bands will be used for military applications, both to avoid crowding the lower bands and to achieve secure communications. On Earth, extensive use will be made of optical cables.

This growth in communication link capacity will be paralleled by a growth in capabilities for data compression and onboard processing. Thus, the system designer will have a wide variety of options to support trade-off analyses, having as one extreme low-cost, large-capacity communication systems, able to transmit all data

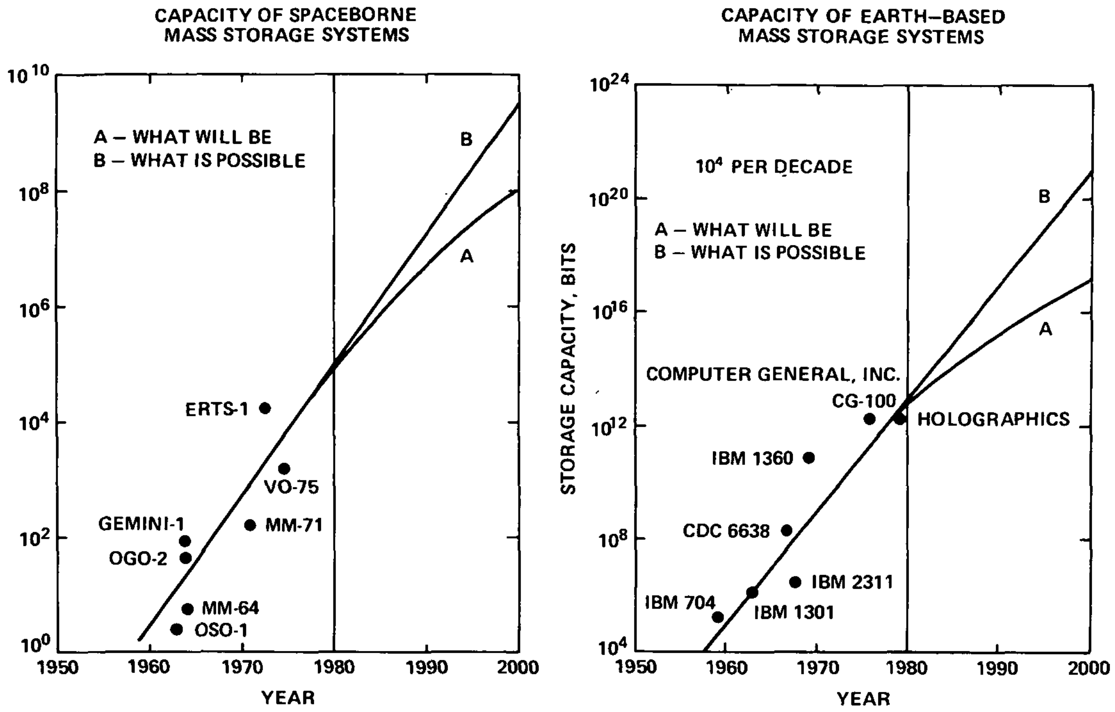


Figure 25. Forecasts of Computer Storage Capacities.

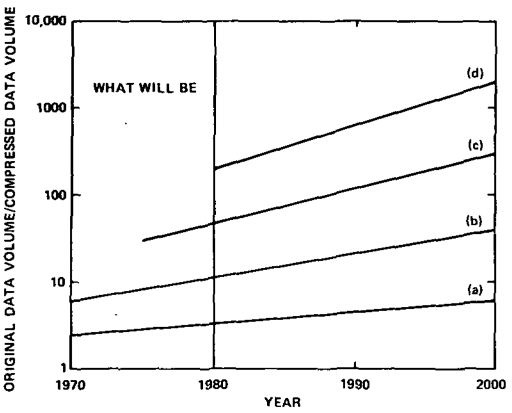
from simple and inexpensive data acquisition systems to central data processing stations on Earth.

LSI will also affect information transfer. More and more, communications systems will consist of integrated transmitters, receivers, and antennas. The antennas will be composed of arrays of small dipole elements mounted on large erectable structures, each connected to its individual receiver. Phasing of electronic elements will point and shape the multi-antenna beams and adjust their polarizations. By this means, extremely large antenna aperture may be achieved. Various transformations of signals with large bandwidths requiring high spectral resolution will be accomplished inexpensively with microprocessors.

Onboard Processing – The implementation of space-borne data processing and control functions will follow commercial trends. The concept of applying dedicated computers to individual functions will be realized on spacecraft by 1985. Initially, these computers (microprocessors) will operate independently to simplify software and hardware complexity. Later, still more dense microcircuits and new software concepts will permit interaction of computer elements at higher levels and provide load-sharing and fault-tolerant operation.

Advances in spacecraft hardware and in a variety of applications programs will promote the transfer of more responsibility to spacecraft. Instruments will become more independent of step-by-step ground control during measurement procedures. Much routine processing of data now performed on Earth will be carried out within the instrument. This advance, and the use of source encoding for data compression, will reduce requirements for channel capacity for space-to-Earth communication links and ease problems of rapid and economical dissemination of mission results.

By the year 2000, the volume of transmitted data required to meet a set of space system objectives will be reduced by a factor of approximately 100 through information extraction and encoding methods. Users will interact with spacecraft image processing systems to select and control the criteria employed in onboard information extraction. The trends in data compression are forecast to occur as shown in Figure 26. In future years, perhaps beyond the year 2000, the in-space information system may organize itself to extract the information from measurement data on the basis of a set of prescribed criteria and constraints.



DISCUSSION

The curves relate to four different classes of applications distinguished by the following fidelity criteria:

(a) Those requiring nearly exact reconstruction of the original source data.
(b) Those requiring an approximate reconstruction of the original source data, such that there is very little perceptible difference between a photograph produced from the compressed data and one produced from the original data.
(c) Those requiring production of a high-resolution thematic map which describes the spatial distrubution of a small number of source "classes" which are recognizable from the spectral properties of original data samples.
(d) Those requiring determination of the location and key parameters of prescribed features which occur infrequently within a survey area.

Figure 26. Forecast of Data Compression Trends

Robotics – The information return from missions on the surfaces of planets or their satellites will be greatly enhanced through the use of advanced robot systems. These will carry out certain operations automatically – for example, the collection and manipulation of rock and soil samples and the control of scientific instruments. Human beings on Earth will plan such actions and initiate them, but will not guide their step-by-step execution. Such methods of supervisory control will also be employed near Earth in teleoperator systems used for Shuttle operations or in the construction of large space structures.

For spacecraft other than surface explorers, similar control methods and more capable and reliable onboard operating systems will provide all classes of spacecraft with an increased autonomy, and ground system control and communications facilities will thus be available to support more missions at a given time than is possible in 1975. Automation of some ground-control functions will reduce the tedium of certain aspects of mission control. All of these advances in spacecraft autonomy will reflect and contribute to similar advances in the automation of similar functions on Earth, especially in industry and in deep-sea exploration.

Software – At present, the generation and use of computer programs present a serious obstacle to the expedient use of computers. Difficulties in planning, estimating, producing, controlling, checking, and maintaining software make it costly. Lack of standardization in machines and in programming languages, rigidity in the format of discourse, and many other limitations impede the interaction between human beings and computers and slow the exchange of useful or valuable information.

Significant software advances are essential to facilitate communication between user and computer for program generation and use, and to take full benefit of more available low-cost computer systems. Although no breakthroughs are foreseen in the complex problems involved, certain developments are likely. Present structured design procedures for the analysis of a processing task into program requirements will mature. There will be some standardization of programming languages, compilers, and hardware. Higher-order languages with syntax closer to English will be developed, with concurrent deemphasis on efficient use of the computer hardware in order to increase the efficiency at the human-computer interface. Computer-generated program listings that clearly communicate the functioning of the program to the human user will be developed. Progress in computer recognition of spoken languages, measured in terms of size of speaker vocabulary allowed and variety of speakers accepted, will significantly affect the human-and-machine interaction.

The impact of these developments will be a reduction in software-generation costs, wider application of computers, and greater transparency of the machine to the user.

The Management of Energy

Overview

The examination of this field is presented in two subcategories: Earth-to-orbit operations, and space power and propulsion.

Over the next 25 years there will be the possibility of developing vehicles capable of lifting very large masses of payload into Earth orbit at low costs. Examples of space activities which would require such capability are the development of satellite power stations, hazardous waste disposal, commercial processing in space, and the exploitation of lunar resources. Although the Shuttle system and derivations of it can bring the cost down significantly from present values to levels below 200 dollars per kilogram, it may be possible to do even better with new heavy-lift vehicles such as single stage to orbit, vertical takeoff and vertical landing (VTOVL) designs with which launch costs could be less than 50 dollars per kilogram.

In the category of space power and propulsion, there will be requirements for more efficient transmission, collection, storage, and conversion of energy for both exploration and application activities in space. In the time frame of interest space power transmission is likely to rely on microwave technology rather than laser technology or other transmission concepts. The most obvious source of energy for collection in space is the Sun, from which photon energy could be collected and then converted to electrical energy by photovoltaic cells, or by thermal conversion systems. In 1975, neither of these approaches can be ruled out in favor of the other. Lunar minerals may offer sources of chemical energy for propulsion purposes, although it will require more energy to gather and process such chemicals than they would yield, implying the need for *in situ* solar or nuclear power stations to take advantage of this possibility.

Energy needs to be stored on spacecraft both for station power requirements and for course-changing propulsion. By far the lowest-mass means for storing energy in space will be nuclear energy, particularly fission reactors developed for space use. Mass-per-unit energy stored and made available as electrical energy can be three orders of magnitude less than with chemical or mechanical storage. Cost of nuclear systems for storing energy is expected to be about the same as chemical systems on an energy mass basis.

Conversion of stored energy to mechanical energy for propulsion use will undoubtedly continue to rely on thermochemical systems for Earth launching over the time period of interest. However, for space propulsion, such as that used for interplanetary flight, additional options may be made available for development before the year 2000. Electrostatic, electromagnetic, and very-high-temperature thermal devices used with fission reactors could accelerate propellants to a new order of magnitude in exhaust velocity. It is not likely that fusion systems or antimatter systems will be available before the turn of the century, but work in these directions might lead to their availability within a few decades thereafter.

Conversion of energy from various sources to electrical energy for spacecraft power can be accomplished with a variety of approaches. Concepts which have received the most attention to date, such as solar photovoltaic and solar thermionic systems, could yield mass efficiencies of the order of 10 kg/kWe for the complete collection and conversion system before the turn of the century. More advanced concepts, such as solar dielectric conversion, might achieve 1 kg/kWe for special applications.

Space propulsion is required for trajectory establishment, stationkeeping, attitude control, and course correction. The first of these is, of course, particularly important when a mission requires high escape velocity from Earth, orbiting of another planet or satellite, or descending to its surface. The fraction of mass that must be devoted to storing energy onboard determines to a large extent, the fraction of spacecraft mass which can be devoted to the payload of instrumentation, communications gear, and so on. Explorations beyond the solar system, perhaps aimed toward other stars, are completely impractical with propulsion systems available in 1975. As such objectives become more desirable, there will be an increasing pressure to develop new and highly efficient propulsion schemes, such as antimatter storage systems.

Technology Forecasts in the Field of Energy

Earth-to-Orbit Space Transportation Systems – To discuss such systems, four possible levels of capability are defined as in Table 27.

Table 27

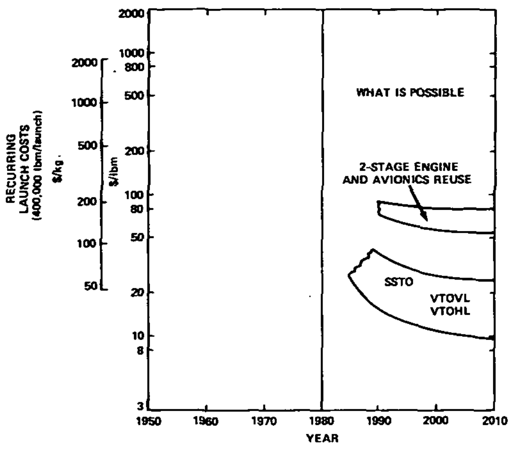
Earth-Orbit Transportation Capabilities

	Payload/Yr [10^6 lbm (kg)/yr]		Payload/Launch [10^3 lbm (kg)]
	Up	Down	Up
Level I	0.5 (0.23)	0	30 (13.5)
Level II	4 (1.8)	1 (0.45)	60 (27)
Level III	20 (9)	2 (0.9)	400 (180)
Level IV	100 (45)	2 (0.9)	2000 (900)

The Shuttle system operating at full capacity could accommodate traffic up to the second level. However, there appear to be recurring cost-reduction incentives for major technology advancements in the Shuttle after the present system has matured. The Level III requirements could be made only by a completely new system. It is estimated that a special vehicle for the Level IV class would not be economical since the economies of scale would already be met at Level III. Level IV annual traffic would be accomplished by more launch sites and flights with a Level III vehicle.

By the year 2000, the recurring flight costs of an upgraded Shuttle (Level II) could be brought down to about 180 dollars per kilogram of payload delivered, and a second generation, fully reusable Shuttle might reduce this cost to about 110 dollars per kilogram. Beyond that, there are a number of other options which seem available, such as a winged, single-stage-to-orbit (SSTO) vehicle or vertical takeoff vertical landing (VTOVL) vehicle, which might bring the cost down to about 50 dollars per kilogram for Level II operations.

A low-cost, heavy-lift vehicle (Level III) for massive transport to orbit can bring recurring costs to a minimum by profiting from such features as single-stage-to-orbit, VTOVL, zero-return payload, no cross range or return, unmanned operation, if used in conjunction with a smaller crew-operated Shuttle vehicle, and optimum combination of high-density and low-density (high performance) propellants. Recurring costs of less than 50 dollars per kilogram delivered to orbit can be envisioned for such Level III systems. The development investment in the new heavy-lift system could range from 8 billion to 10 billion dollars. Possibilities are shown in Figure 27.



DISCUSSION

The vehicles are all variants of single-stage-to-orbit vehicles landing either horizontally like the Shuttle or vertically with heat shields, various aerodynamic devices, and a short engine firing for hovering vertical descent to Earth. To permit SSTO operation, various means of assisting the vehicle to achieve velocity and altitude are airborne launch, external propellant tanks and strap-on rocket propulsion units. Launch costs for these concepts are predicted to be in the $15 to $30/lbm ($33 to $66/kg) range.

Two basic classes of vehicles are considered. The more expensive in terms of costs per pound in orbit are the two-stage vehicles with the first stage built from Shuttle components and recoverable. Second stages are unmanned, with recoverable engines and avionics, employing either orbital recovery or components or encapsulating the high-value components in an entry body. These vehicles yielded launch costs in the $75/lbm ($165/kg) range for the year 2000.

Figure 27. Heavy-lift Launch Vehicle Possibilities Beyond the Shuttle

At all levels of operation, high-pressure hydrogen/oxygen engines, possibly augmented by engines burning higher-density propellants in the early part of the boost, will likely continue to find advantageous use.

It is observed that there are many feasible approaches to reducing Earth-to-orbit recurring mission costs to a level of 50 dollars per kilogram by the year 2000, provided program requirements generate the need to launch numerous large payloads and hence the rationale for the large nonrecurring investment implied for the new developments. The following forecasts address the subcategory of Space Power and Propulsion Systems.

Energy Transmission – Only laser and microwave beam systems are considered to be feasible during the next 25 years for transmitting large amounts of power between systems in space or between the Earth and space, with the microwave systems being the most advanced and appearing to be the most desirable for use in cislunar space over the time period in question. The high-efficiency and high-power density predicted for microwave beams will be made available for space applications to a large extent through industrial development without major NASA support. Microwave beams can be collected by means of high-efficiency rectennas (rectifier-antennas) with masses on the order of a few kg/kW of beam power received. Overall transmission efficiency (DC power out of receiver/DC power into transmitter) of more than 70% can be envisioned by the year 2000.

Laser beams, collected by photovoltaic cells and converted to electrical power, might be of use in special applications, particularly when longer distances than Earth orbital are involved. Even though the projected efficiency of laser power transmission systems (≈ 10%) is considerably below that projected for microwave systems, the areas required for transmission and reception are only 10^{-4} as large.

Energy Collection – Photovoltaic systems are the primary means of collecting energy in space for spacecraft in use in 1975, and will very likely continue in that role. It is reasonable to expect that such systems will also be used at a very large scale if satellite solar power stations should become practicable. However, there are some advantages in the use of large concentrators with thermal conversion by heat engines. In particular, this approach is more resistive to degradation from high-energy particles such as would be encountered in the radiation belts around the Earth.

Extraterrestrial materials can be collected and processed into chemical constituents which store the energy. This would, of course, require the development of either solar or nuclear energy sources to provide the necessary primary energy source, and, in fact, the net energy available would be less than that originally supplied. For example, electrolysis of water ice to make chemical reactants for power or propulsion requires an input energy of approximately 2.5 times the energy that can be recovered by later reaction of the chemicals. Nevertheless, such collection and conversion may be desirable as a means of providing energy which can be transported from the primary energy sites or can support peak loads; the primary power plants would, of course, be used for other purposes at such an extraterrestrial site.

Energy Storage – On the basis of storage and electrical conversion systems mass-per-unit of stored energy, primary batteries, stable chemicals, and flywheels are competitive. Forecast mass ratios for these devices by the year 2000 range from 10^{-6} to 10^{-7} kg/J. Neither metastable chemical systems nor superconducting magnetic systems appear to offer any particular advantages with regard to this parameter.

For large amounts of energy storage such as that required for space bases or for propulsion, fission nuclear devices offer very great reductions (factors of 10^3) in mass-per-unit stored energy, when compared with any other devices expected to be available before the year 2000. Nuclear device cost-per-unit of energy stored should be similar to that of chemical systems.

Conversion to Mechanical Energy for Propulsion – Since the variety of propulsion needs is great, no single system will dominate this field. Chemical propulsion will continue to be used extensively throughout the period. However, for missions which require extremely high velocity increments, such as solar system exploration, other propulsion systems will be employed once the spacecraft is in orbit. Solar electric and laser electric systems should show cost advantages over chemical systems for such missions, as well as for raising an orbit from low altitude to synchronous altitude and return. Solar sailing may offer cost advantages for missions with modest payload mass operating at distances of the order of 1 A.U. from the Sun or less. Toward the end of the time period, it is likely that nuclear electric propulsion and power devices may dominate high-energy missions to the outer portions of the solar system. Such systems would permit the delivery of very large payloads to and from the outer planets with trip times held to several years, and crew operated missions to the near planets with trip times of less than a year.

It is likely that, by the year 2000, advanced hydrogen-heating nuclear thrusters, such as the dustbed concept or the gas-core concept, could be brought into being, yielding exhaust velocities comparable to those of nuclear electric systems but with greatly reduced energy conversion system mass. Other even more advanced ideas might be on the horizon by the turn of the century: fusion systems or even antimatter systems.

Advanced propulsion systems will only be implemented if there is a specific mission demand for high performance. One-half to one billion dollars and long development lead times (10 years) would be needed to bring nuclear electric propulsion into being. It seems likely that a space nuclear fission power source in the 100 kWe to 500 kWe size range will be developed in the time period of interest. This device, used with electric thrusters, will then take its place along with chemical propulsion, solar electric propulsion, and solar sailing in establishing the space transportation capability of this century.

Conversion to Electrical Energy – A number of conversion concepts were examined in this category, corresponding to a variety of different input/output requirements and power levels. Most of the systems indicate mass-per-unit power parameters of the order of 10 to 100 kg/kW. The solar dielectric concept could conceivably be used to convert solar energy to electricity at a mass of 10^1 kg/kW for low-power spinning spacecraft. Even lower mass/power ratios will be possible with very large magnetogasdynamic converters. The advances of major importance forecast for energy conversion to electrical energy are:

1. Order of magnitude reductions in the costs and specific mass of large photovoltaic solar energy conversion arrays.
2. The use of thermionics for radioisotope energy conversion with a factor of 6 reduction in mass-per-unit power when compared with presently used thermoelectric converters.
3. For very-high-power (multimegawatt) systems with either chemical or nuclear sources, magnetogasdynamic converters will provide low specific mass (0.3 kg/kWe) and potentially long lifetime.

A summary of the forecasts of conversion to electrical energy is shown in Table 28.

Management of Matter

Overview

Space missions of the future will continue to demand structures with high strength-to-weight ratios, long-life microelectronic components, reliable protection and support of components and crew, and accurate positioning and guidance. Pressure for low cost will continue to be great, and it will determine not only how much can be done on a particular mission, but whether or not the mission will be flown at all. For example, satellite solar power stations will come into widespread use if they

Table 28

Conversion to Electrical Energy Summary

Conversion Device	α_c = kg/We	
	1975 - 1985	2000
Ambient field tapping	1.3×10^{-2}	1.2×10^{-2}
Solar photovoltaic	3.3×10^{-2}	7.6×10^{-3}
Solar thermionic	7.3×10^{-2}	2.8×10^{-2}
Solar dielectric	4.0×10^{-3}	4.0×10^{-4}
MGD system (chemical 5 MWe, excludes reactants)	1.5×10^{-3}	2.5×10^{-4}
RTIG (thermionics includes isotope)	1.7×10^{-2}	1.4×10^{-2}
MGD system (Fission, 100 MWe, includes reactor)	–	3.4×10^{-3}

demonstrate an economic advantage, but will not progress even beyond the prototype stage if they cannot demonstrate such an advantage. It is important then that technology advances continue for a wide variety of new materials coupled with increasingly powerful techniques of design analysis. This will result in major improvements in the weight, cost, and reliability characteristics of space systems.

Future space missions will require significant improvements in onboard data handling capability. High-density data processing systems and memories with low power requirements will be essential. Communications will demand large antennas capable of being accurately aimed at their receivers. New possibilities in space applications will be either practical or impractical, depending on whether or not extremely large (many square kilometers in extent) low-weight structures can be assembled and controlled in Earth-orbit at low cost.

This field of technology includes the placement and positioning of matter. One could always specify a requirement for accuracy of positioning or guidance beyond any quoted number, so there is probably no such thing as "sufficient" accuracy. However, considering the wide range of missions conceivable between now and the turn of the century, advances in guidance and control technology will provide the capability of satisfying practical demands.

Entry into the atmosphere of another planet, or landing on the surface of another planet or its satellites, will require accuracies similar to those demanded for re-entry to the Earth's atmosphere on return from the Moon. However, for planetary exploration, this accuracy must be provided at a remote distance, with moment-by-moment corrections generated by the spacecraft system itself.

Human operations in Earth-orbit and on the surface of the Moon may offer considerable economic benefits. Some missions could be carried out by crews of only a few individuals staying in space for a matter of weeks. This capability has already been demonstrated. However, for missions requiring larger crew sizes and durations of years in an extraterrestrial environment, the problem of resupplying food, water, oxygen, and other needs is a very major challenge.

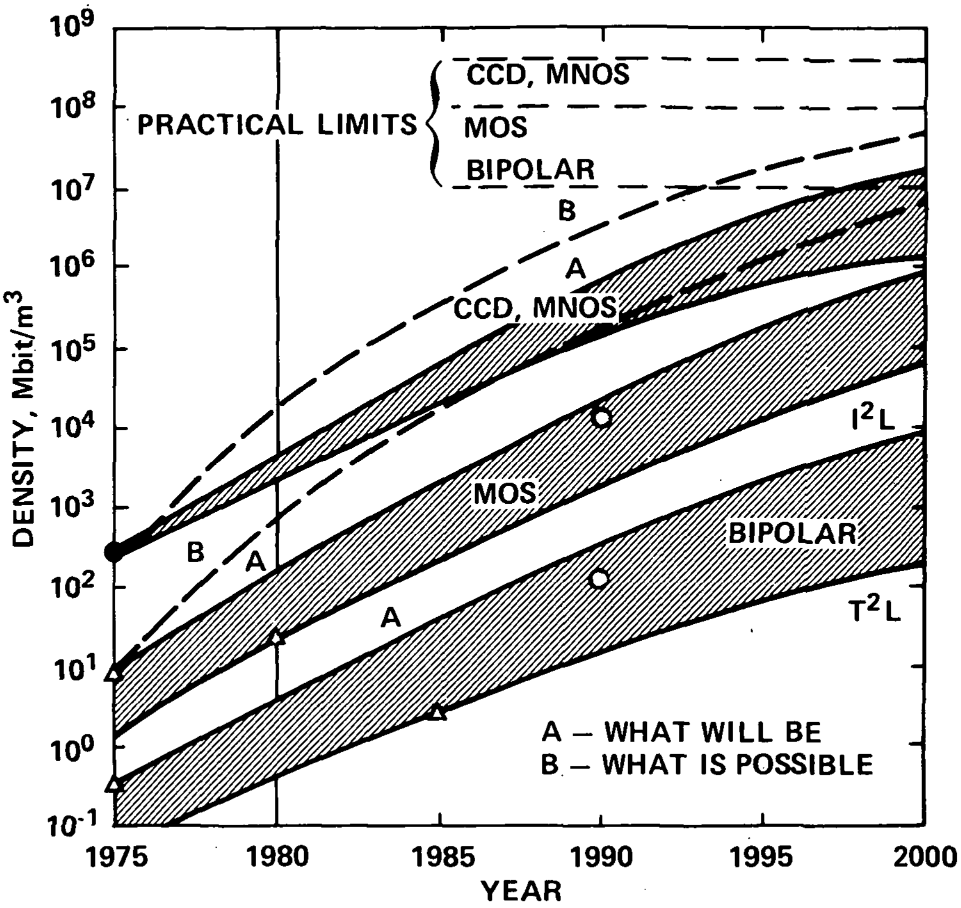
The field of technology which limits many space activities relates to life-support systems. The 1975 technology does not provide substantial capability for recycling human wastes: gases, liquids, or solids. Nor is there yet any medical solution to such problems as the zero-g calcium loss from bones. Satisfactory solutions to problems such as these will require some years.

There is a continuing need to protect human crews and a number of sensitive instruments from the space environment by providing adequate pressure containment, thermal protection, and radiation shielding. In addition, there are likely to be special needs such as the requirement to maintain superconducting elements at a sufficiently low temperature for long periods of time and the requirement to adequately seal samples of material returned from the surface of Mars, or radioactive waste products delivered for disposal to interplanetary space.

Technology Forecasts in the Field of Matter

Microelectronics – Advances in microelectronics have been rapid over the last several years and will likely continue to be so, as shown in Figure 28, a forecast of semiconductor system density taken from the Reference Volume. Both costs and power requirements will be steadily reduced while reliability and speed will increase. Artificial intelligence and robotics will be practical to implement in spacecraft. There will be a particularly important growth in the capabilities of data storage, using both semiconductors and magnetic bubble systems. By the end of the 1980s, storage systems such as optical memories using laser/read-write and holographic techniques, will be capable of storing data at a density of 10^{14} bits per cubic meter. It is also possible that a variety of superconductor elements will become available in the 1980s, at least for ground-based computers. In general, the microelectronics picture is quite encouraging. This area of technology is not likely to place any limitations on space missions in the remainder of this century with but one major exception: the configuring of these dense microcomponents into reliable systems.

Materials and Large Space Structures – The ability to assemble and control large structures in space has yet to be demonstrated. However, there are a number of developments which indicate that this will become practical. Metal matrix and polymer matrix composites will play a very significant role in realizing large, efficient space structures. The use of composites will provide a 30% to 50% saving in structural weight, as is shown in Figure 29, and a reduction by two orders of magnitude in thermal distortion of extended structures such as antennas, reflectors, and solar arrays. By the use of beryllium and beryllium-aluminum alloys, a four-fold increase in



DISCUSSION

The "What will be" forecasts are based on commercially driven projections with the shaded bands encompassing a range of device design options (e.g., PMOS, CMOS and CMOS-SOS in MOS band). The "What is possible" curves could result from modest government investments (on the order of millions of dollars) in the early research and development phase of high-density technology to spur industry on.

The projections take into account the system overhead which include power supplies, heat transfer, interconnects, etc. The data point (●) is a developmental CCD system built by RCA (Electronic Design, 1974). The points (o) from Turn (Ref. 35) are based on maximum power density (i.e., heat dissipation limitation) and represent a conservative upper estimate corresponding to the anticipated density of gates on silicon chips at the time. The points (Δ) of Martin (Ref. 36) are more conservative forecasts based on today's system overhead requirements and can be considered a lower limit. Clearly, the system overhead becomes less important with increasing density of gates on chips.

The overall practical limits on density are set by the combination of the maximum density of bits per chip, and the maximum stacking density of chips. The stacking density is limited by practical mechanical considerations. The density on a chip is limited by random fluctuations of device parameters due to the small number of dopant atoms in a small region, and the maximum electric fields that can be tolerated.

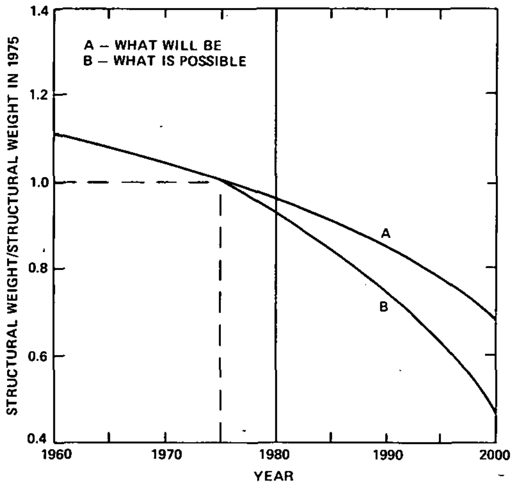
The density increases out to 1985 will be primarily due to the development of technology which provides increased density of gates on a chip and some increase in chip size, reaching a limit of about 10^7 gates per chip in CCD or MNOS. This limit will be achieved by high-resolution lithography (e.g., electron beam or X-ray) and the use of thin oxides presently under active research. Beyond that point, increasing system density will continue through the development of more advanced interconnect and packaging techniques, including three dimensional stacking of chips.

CCD and MNOS densities are higher than other MOS technologies (CMOS, PMOS, NMOS, etc.) because of the inherently smaller areas required for a single gate function. Bipolar devices require still more area and also are limited by higher power dissipation, with |2L (integrated injection logic) offering the highest density.

System weight can be computed by multiplying the system volume obtained from the above forecast by a typical value of mass density, estimated to be 200 kg/m^3 in 1980 and increasing to about 500 kg/m^3 by the end of the century, as higher packing densities are achieved.

Figure 28. Density of Semiconductor Systems

stiffness per unit density can be achieved. Improved polymers will provide a three-fold increase in adhesive toughness, strength, and durability. The steady growth of attitude control technology will permit accurate pointing of solar arrays of the order of a square kilometer in area before the turn of the century. Antennas require more accuracy in pointing, but this accuracy can be achieved for areas of tens of thousands of square meters before the turn of the century.



DISCUSSION

The A curve, showing a 30% reduction in structural weight by the year 2000, is based on the use of composites and structural concepts which will evolve naturally. The 50% reduction in structural weight shown in the B curve depends not only on the full utilization of the unique properties of composites, but also on development of structural concepts using new and different structural analysis and design techniques.

Figure 29. Structural Weight Reduction for Space Systems

Clearly, a considerable development effort is required to learn how to assemble and control such huge structures, and undoubtedly this will require considerable advancement in our abilities to carry out human extravehicular activities. However, a research and technological advancement program aimed toward this objective can be planned with confidence that the basic technologies of structures, materials, and control techniques will be available.

Major advances will continue to be made in all areas of structural materials, and not by concentrated efforts devoted to only a few materials or structures systems.

Superalloys and refractory metals which use temperatures of 1200°C will make efficient space radiators and reusable heat shields. Computer-aided analysis and design methods will result in faster, lower-cost vehicle design cycles. Active controls on launch and reentry vehicles will provide 50% alleviation of gust loads. Fire-resistant, high-temperature polymers will continue to be developed, leading to greater space vehicle safety. In the area of space processing, breakthroughs will be made in the homogeneity and purity of semiconducting materials, as well as the production of materials with unique mechanical and electrical properties. It is likely that in the zero-gravity environment, ultrasmooth, pure, non-nucleated materials can be formed with controlled shapes.

Guidance and Control for the Transfer of Matter – Technologies required for this objective are currently well developed and will continue to improve. With the advent of such techniques as differential very long baseline interferometry (ΔVLBI), onboard optical and pulsar navigation techniques for the delivery of spacecraft to the inner and outer planets will have accuracies in the range of 2 to 20 kilometers. Delivery accuracies to comets and asteroids is shown in Figure 30. Position accuracy of orbiters around the planets will be better than a few kilometers, and will be approaching 2 to 20 centimeters for spacecraft orbiting the Earth. It will be possible to control the entry corridor into the atmosphere of Venus, for example, to 0.2 degree and to locate a roving vehicle on Mars or the Moon to within the order of 0.001% of the distance to a referenced landmark. Spacecraft instrument pointing accuracy will improve to 0.005 degree for interplanetary spacecraft and to 0.0001 degree for Earth-orbiting spacecraft.

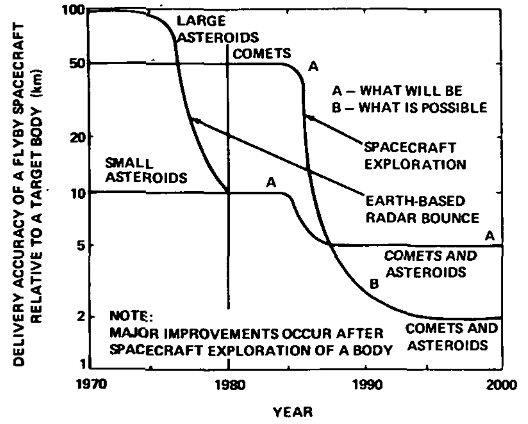
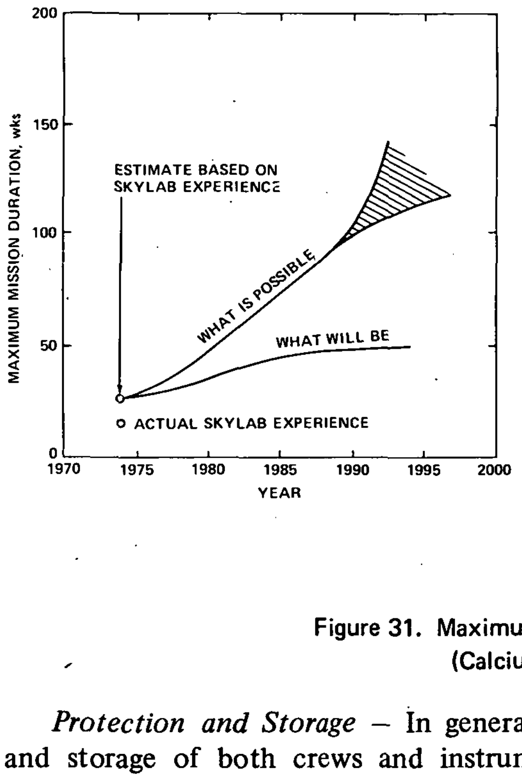


Figure 30. Delivery Accuracy to Comets and Asteroids

Life-Support Systems – As yet, no fully closed, fully recycling life-support system has been built which can accommodate human beings. Small closed systems have supported minute marine animals for extended periods of time, which indicates that the concept is at least feasible; however, much work remains before a system for human beings can be fully recycling. Chemical-physical techniques are available for recycling CO_2, O_2, and water. It does not seem possible, however, to grow food plants directly on human waste products in an otherwise sterile environment. Decomposing organisms must be included, and this implies the need for a complex ecological system in which only a portion of the primary product of photosynthesis would be available for human consumption. On the basis of present knowledge, it would be unreasonable to predict long-term success of a closed ecological system smaller than about one hectare per person. However, it would be perfectly reasonable to begin experiments with smaller acreages and carefully controlled environments. By the very nature of biological processes, it would take several years to determine whether or not such limited ecosystems could be maintained stably over extended periods. If experiments in this direction are initiated at an early date, it should be possible by the year 2000 to bring down the area requirements for a space farm to a fraction of a hectare per capita. It might be difficult even then to guarantee that the system could be absolutely closed, but at least the resupply requirements could be reduced to a minor fraction of the overall mission cost.

Space Medicine – A number of problems in space medicine require attention and research both in Earth-based laboratories and in orbiting stations. Those which appear to be the most critical are problems encountered by long duration at zero or fractional gravity, such as bone resportion (see Figure 31), cardiovascular effects, and maintenance of muscle mass and neuromuscular coordination; psychological effects on crew behavior for very extended missions in comparatively confined quarters; and radiation hazard. Clearly a final solution to such problems will require extensive experimentation with both laboratory animals and human beings at various levels of gravity. Thus, an extensive space-station research program must be considered a prerequisite to any long-duration space mission, coordinated with a parallel program in Earth-based research laboratories.



DISCUSSION

The starting point in 1974 corresponds to twice the length of the longest Skylab mission and is based on medical information gained during that mission. The data indicate that under Skylab conditions, a duration of 24 weeks would have been feasible.

The "What Will Be" curve assumes Skylab conditions would be improved by optimizing diet (e.g., total Ca and Ca/P ratio) and exercise based on data obtained from completed Skylab missions.

The "What is Possible" curve assumes that intensive work on experimental animals and humans under appropriate conditions will yield data on which clinical management for calcium loss could be based (presently available data are not adequate). Thereafter, it is assumed that there would be a carefully supervised treatment of astronauts with those hormones, vitamins and minerals that are directly involved in the maintenance of normal bone.

The uncertainty as to what is possible after 1990 presumes that research has indicated techniques for maintaining normal bone formation in the absence of gravity. The possibility of such artificial stimulation (e.g., application of precisely controlled magnetic fields and/or weak electric currents) is quite speculative at present; thus, the uncertainty at the later time period.

Figure 31. Maximum Mission Duration at Zero-g
(Calcium-loss Limited)

Protection and Storage – In general, the technology available for the protection and storage of both crews and instruments is well developed and will continue to progress. There will be improvements in meteoroid and radiation shielding. There are other areas in which the technology will advance with significant education in the cost of employing the capability. An example is providing cryogenic storage over long periods for large superconducting systems, in which the power consumption of the refrigerator currently outweighs the potential advantages of using superconductors.

The technical problems do not appear to be major in providing reliable containment of dangerous solids such as nuclear wastes or biological samples.

However, no container is guaranteed to be absolutely safe with a 100% probability and, therefore, failure rate specifications that are so small as to exceed technical feasibility will call for systems synthesized to provide redundant capabilities and safeguards.

Some highlights of the technology forecast are summarized in Table 29.

Table 29

Highlights of Technology Forecast

INFORMATION

- Requisite communication link capacities
- Dramatic increase in storage/processor density
- Greater use of dedicated, distributed processors
- Considerably greater machine autonomy
- Evolutionary progress in software cost — no breakthroughs
- Higher-order languages, machine recognition of spoken word

ENERGY

- $50/kg to low Earth orbit
- Continued extensive use of chemical propulsion
- Large power transmission via microwave
- Use of photovoltaics and large concentrators for major power sources
- Fission nuclear devices offer 10^3 reduction in mass per unit energy stored
- Nuclear electric propulsion for high energy mission
- Thermionic-radioisotope conversion x 1/10 reduction in mass per unit power vs. thermoelectric converters

MATTER

- Storage of 10^{14} bits per cubic meter
- Structural weights x 1/2 through metal and polymer matrix composites
- Several square kilometers, deployed and pointed accurately in space
- Super alloys and refractory metals for 1200°C use
- Delivery to the outer planets with 50-km accuracy
- Virtually fully closed, recycling biological life support systems
- Solutions to bone resorption, cardiovascular, and other weightlessness effects
- Requisite self-repair, redundancy for microcomponents exploitation

Technology Emphasis for the Future

In Chapters 5 and 7 we have examined a number of future space objectives, and in this chapter, we have summarized the prospects of technology for the remainder of this century.

With this background, the function of this section is to identify additional selected areas of technology which will require emphasis over the next 25 years in order that the nation will be prepared to embark on the more attractive systems that are now known, or which might emerge, with acceptable risks.

This recognizes as a reference the currently well-balanced deployment of support to space-related research and technological advancement and it is not intended that this be disturbed. Rather it is proposed that the areas discussed in this section be regarded as "add-ons" for preparedness. The actual proportions and timing of additional emphasis are, of course, quite dependent upon the target dates selected for the achievement of those candidate objectives which eventually become a part of the total national program.

The areas for which additional emphasis is advocated are summarized in Table 30, in no particular order. They generally have the following characteristics:

1. They are thought to be the advances that have the greatest impact on the future candidate space objectives.
2. As a rule, they affect a broad spectrum of candidate space objectives.
3. They are mainly peculiar to space activities, and we can therefore expect little initial support for their advancement from commercial or non-space government sources. Eventually (as was the case with communication satellites), many objectives, once demonstrated as feasible and cost effective, will begin to attract the industry, with its venture capital, and the cooperative support of other governmental agencies.

Table 30

Preparedness Technology Selected for
Special Emphasis

- Very Large Scale and Lower Cost:
    - Space Transportation
    - Controllable Lightweight Structures
    - Space Energy Converters
    - Antenna Apertures and Arraying
- Very Long Life Components and Systems
- Large-Scale, Reliable Microcomponent Utilization
- Autonomous Spacecraft and Vehicles
- Precision Navigation
- Instruments and Sensors
- Nuclear Space Power and Propulsion Systems
- Advanced Propulsion
- Closed Ecological and Life Support Systems
- Long Flight Physio-Phycho-Socio Implications
- Lunar Resource Recovery, Processing, and Space Station Manufacturing in Orbit
- Planetary Environment Engineering
- Large-Scale End-to-End Information Management

A discussion of each of the areas follows:

Space Transportation – Larger Scale, Lower Cost

The advancement of space transportation technology continues as a dominant need for certain missions, not because the missions are basically unfeasible with present capabilities but because their cost would be prohibitive. The Shuttle transportation system, expanded to full capability, could give both more flexibility and lower cost for a variety of missions envisioned for the next 10 to 15 years. For more advanced missions, such as large orbital power plant, nuclear waste disposal, assembly and processing operations in space, and eventually bases or outposts in space, a new heavy-lift vehicle can reduce by a factor of three or more the cost of lifting massive quantities of material to low Earth-orbit. This reduction will more than compensate for a large development cost for the new vehicle system.

Controllable, Lightweight, Large-Scale Structures

A complete new technology is needed for such structures so that they can be delivered into space, unpacked, assembled, and maintained with the required precision in orientation, shape, thermal stability, and rigidity. Some of these structures will have dimensions of the order of a kilometer and in many cases the shapes of their surfaces will have to be controlled by servomechanisms to within centimeters or millimeters. Examples of such structures in the future catalogue of space activities include very large microwave reflectors and antennas, solar energy collectors and radiators, solar sails, telescopes, and enclosures for farms and habitats. In addition to structural integrity and shape control, the dynamic interactions involved in the pointing control of such are unprecedented.

Very Large-Scale, Lower-Cost Space Energy Converters

The attractiveness of collecting solar power in space and beaming it back to Earth depends on the development of either low-cost photovoltaic solar arrays with thermal converters, or solar energy concentrators deployed on extremely lightweight structures. In the use of photovoltaic arrays, the high voltages and multi-gigawatt power levels imply that the structural array must have insulating properties. The complete structure should be adaptable to assembly space and subsequent maintenance-free operation for many years. The interactions of efficiency, radiation susceptibility, temperature, and lightweight requirements, along with the need to reduce the cost of such arrays by orders of magnitude, present a major challenge. In the case of the concentrators with thermal converters, the problems of orientation, shape, thermal stability, and rigidity of large-scale structures must be solved.

Large-Scale Antenna Apertures and Arraying

Large antenna apertures – for use on Earth, in Earth orbit, and on the Moon for radio astronomy, deep-space communications, precise location measuring, radio guidance, crystal motion measurements, and ultra-long baseline interferometry – are applicable to a wide spectrum of candidate space objectives. Low-cost methods for the precise arraying of small element dipoles and large erectable structures are needed for achieving large aperatures at low system noise temperatures, and, for electronically steering multiple antenna beams by exploiting LSI and microprocessor technology.

Very Long Life Components/Systems

Many of the candidate objectives warrant the employment of space activities only if the capitalization cost of the missions or systems can be amortized over a long period of time, requiring little maintenance or resupply. For example, a space solar power station can be competitive with a fossil fuel station on Earth, not only as a consequence of a reduction in the cost of the energy conversion system and transportation to orbit, but also simply through its operation over many maintenance-free years in space.

Systems properly designed for the purpose actually find space a benign environment. Thus, the unique environment of space itself offers the opportunity for space application systems to compete with Earth-based systems. Concomitantly, deep-space missions, by the very nature of their long flights to their targets, demand long-life systems lasting for decades.

Reliable Large-Scale Microcomponent Utilization

The miniaturization of components will continue, altering the whole architecture of space and Earth information systems leading, for example, to distributed systems with balanced use of standardized and customized processor elements, arrayed in optimum fashion for their tasks.

Ultra-high-density microelectronics for information storage is an example of a prerequisite to an enhanced information management capability. Mass memory of 10^7 bits will be stored on a silicon chip less than one square centimeter in area; present devices can hold less than 10^4 bits/chip. As we have mentioned earlier, industry will push ahead in this field, but space agency support is needed to achieve the necessary reliability. The potential use of such large quantities of active devices places extraordinary demands on systems reliability. Such systems must be either component fault-free, heavily redundant, self-repairing, or a combination of all those attributes.

Because of the unique cost of maintenance operations in space, the burden of achieving the needed reliability in the use of such large quantities of these devices is not likely to be borne without federal support.

Autonomous Spacecraft and Vehicles

The uniqueness and vastness of the space environment both requires and permits human beings to venture there with their surrogate machines more extensively than to some regions on Earth, thus a large share of the burden of the development of autonomous machines rests with the space agency.

In all of the activities that we examined in the study, a relationship between human operators and machines in space is implied. Whether the humans are in the machines, or on the surface of the Moon, the Earth, or other planets, there exists a multitude of operator-machine control loops. Already we have seen the early steps in a technology aimed at developing adaptive human supervisory control of machines having some degree of autonomy. This technique appears to offer a good potential for enhancing performance, improving cost and cost-certainty, and increasing the probability of success for many space activities. The use of semi-autonomous robots will call for onboard capabilities approximating those of present-day commercial mini-computers, plus visual, manipulative, and analytical instrumentations sufficient to permit a real time (except for propagation delay), high-level interaction between humans and machines. These capabilities imply kHz to MHz channel rates, megabit onboard storage, microsecond operation times, and four- to ten-level hierarchical command structure. The high-density data storage and end-to-end information management technologies discussed elsewhere in this report contribute to achieving these capabilities.

Efficient execution of tasks at a remote site requires higher levels of autonomy and removal of human beings from the sensorimotor control loop, yet retention of their involvement in planning, decision making, and problem solving. To perform even the simplest tasks autonomously, machines must be able to acquire data from their environment; build models of them that incorporate prior knowledge, physical laws, and common sense; and use these models as the context for task execution and problem solving. Such abilities under human direction can yield returns of scientific information a hundred times greater than that provided by 1975 control methods. These same techniques could then be used to reduce the cost of operations on Earth.

In deep space, missions requiring fast-reaction, round-trip flight times make Earth-based navigation and control impractical. At such remote locations, machine autonomy is required to move safely from one location to another, determine current location, implement control sequences, and provide a desired set of dynamic states independent of unexpected internal or external forces, equipment failures, or other unexpected occurrences.

Precise Navigation

Highly accurate knowledge of in-orbit position is intrinsic to many of the candidate activities we studied. Order-of-magnitude improvements are required in gravity models, station location accuracies, and atmospheric density effects, with companion efforts in multilateriation techniques for Earth-orbit determination.

Navigation delivery accuracy to the inner and outer planets using Earth-based radiometric data is limited by the low declination of the target planet as viewed from Earth and by errors in the planetary ephemerides in directions not observable to Earth-based tracking systems. The low declination limitations will disappear when ΔVLBI navigation techniques come into widespread use.

The planetary ephemerides need to be transferred to an extragalactic radio source coordinate system which will eventually permit angle measurements to spacecraft of 0.01″ of arc when used in conjunction with ΔVLBI.

Instruments and Sensors

Substantial upgrading of instrumentation which is peculiar to space ventures is called for by the candidate objectives responsive to both the physical needs and human needs to understand. Instrument capabilities may be drastically enhanced by technology advancement in space cryogenics and large lightweight optical systems. Most advanced detectors of infrared and microwave radiators, as well as some of the more powerful nuclear and gamma-ray detectors, rely on cooling to cyrogenic, sometimes superconducting, temperatures to achieve necessary sensitivities. Some non-NASA support may be expected in cryogenic technology.

Lightweight optical systems employing continuously adaptable optical surfaces formed of multiple elements permit extraordinary growth in the light-gathering capacity for both astronomical and remote-sensing applications.

In the use of infrared techniques the future requirements to measure true atmospheric constituents are beyond 1975 instrument capabilities in a number of instances.

Nuclear Space Power and Propulsion Systems

The specific mass and cost benefits of nuclear power capabilities in space have been previously mentioned and are a necessary complement to solar power for many applications.

High levels of operational power must be supplied for long duration in situations where solar energy is not available. The cost-effective solution is the employment of nuclear energy storage converted to tens of kilowatts to megawatts of electric power in space.

The shielding, safety, and waste disposal aspects of nuclear power in space are amenable to solution but require special emphasis.

Radioisotopes provide a very efficient mechanism for storing energy. When used at power levels below 10 kWe in conjunction with thermoelectric or thermionic conversion, radioisotopes provide electrical energy on a mass-per-unit energy basis three to four orders of magnitude more favorable than electrochemical batteries. Projected improvements in thermoelectric or thermionic converters and in isotopic fuel can significantly reduce costs from 1975 levels.

For larger orders of energy and power, 100 kWe to multi-megawatt nuclear fission reactors will hold the same level of mass-per-unit energy stored and reduce energy storage costs one to two orders of magnitude below that possible with radioisotopes. Development of a fission nuclear power system of 100 to 500 kWe is advocated for providing power for spacecraft and landed stations and for advanced propulsion in the last decade of the century. If nuclear propulsion is to be used for high-load transportation, such as placement of solar power stations in synchronous orbit, multi-megawatt systems should be produced.

Advanced Propulsion

Storing and processing energy for propulsive purposes is one of the few major cost drivers in accomplishing two major classes of missions:

- Highly energetic missions:
  - to the edge of the solar system and beyond

  - to the close vicinity of the Sun
  - out-of-the-ecliptic plane
  - to landings and returns from extraterrestrial bodies
- Missions requiring transport of very large amounts of matter:
  - nuclear waste disposal
  - solar or nuclear power stations in space
  - bases on the Moon
  - large stations in orbit

These missions could be achieved with energy stored in stable chemical propulsion systems having the necessary number of stages.

However, the high costs associated with the required large mass leaving the Earth and the long flight durations can be drastically reduced by the use of systems which accelerate the exhaust mass to very high velocity by electric or magnetic means and which employ energy stored in the nuclear states of matter or collected from the solar radiation in space.

An examination of candidate objectives presents a strong case for the development of solar and nuclear fission electric propulsion in the next 20 years. An early capability would provide a propulsion system specific mass in the order of 23 kg/kWe at propellant exhaust velocities of 2×10^4 to 10×10^4 m/s and thrust levels of up to 20 newtons.

Even more advanced propulsion concepts which would be brought into operation after the turn of the century offer the prospect of system mass-per-unit power levels two to three orders of magnitude less than is possible with currently envisioned solar and nuclear electric propulsion. Comparable exhaust velocities can be maintained. Such characteristics will enable travel into interstellar space with reasonable mission times. Candidates for this class of propulsion system include:

- Gas-core nuclear fission rockets
- Fusion microexplosion rockets
- Metastable hydrogen rockets

Closed Ecological Life Support Systems

At a certain crew size and duration in space, the cost, weight, and complexity associated with a closed life-support system becomes less than that of resupplying expendables from Earth. A number of attractive space objectives will ultimately reach this trade-off point, and since the development lead time is very long, it is strongly advocated that this general technology advancement begin with the last quarter of this century.

At this juncture, the success of any particular design for closed ecological systems cannot be assured. Whether the recycling of all gases, solids, and liquids can best be done by purely biological processes, or whether certain steps are better done by non-biological chemical-physical subsystems, is not known but must be determined. Even though it might not be possible to guarantee long-term fully-closed operation, a vigorous pursuit of this technology should substantially reduce resupply requirements.

Monitoring and control systems need to be developed for temperature, humidity, and probably for CO_2, particulate and bacteria matter and trace contaminants, even if major recycling is accomplished biologically.

Long Flight Physio-Psycho-Socio Implications

As increased numbers of human beings spend more time in space, the physiological implications previously discussed in this chapter under "Space Medicine" must be understood and dealt with.

Consideration must be given to the appropriate forms of social order for large space ventures involving people. Though the form that this order might take in a small, isolated community is now unknown, its components can be imagined under the title "Quality of Life," and they would include communications, aesthetics, education, law, entertainment, work products, and other such elements that are recognized as the hallmark of successful human communities on Earth.

Lunar Resource Recovery and Processing, and Manufacturing at Space Stations in Orbit

At some point in the future, it will become cost effective to process some minerals into products on the Moon and transport them to facilities in Earth-orbit or possibly on Earth. Such resources would ease the pressure on the demand for energy and minerals on the Earth. Oxygen for life support and propulsion are present on the Moon; in addition to metals (e.g., aluminum, magnesium, iron, titanium) for structural materials and propulsion; ceramics and glasses for construction; silicon for photovoltaic devices; and thorium for nuclear breeder reactor fuels. The special requirements of lunar resource recovery and of processing in Earth-orbit and lunar environments are quite different from those typical of Earth. They need to be examined now, and developed over the next one or two decades to prepare for candidate opportunities.

The in-orbit assembly of small components or modules sent from Earth into large structures will become necessary. But it may be economically desirable to undertake much more extensive industrial activities in a space station, using lunar mineral resources. A rotating station could provide a variety of gravitational fields from zero-g to normal or beyond, as well as uninterrupted solar power. Exploiting this possibility will require the special manufacturing techniques appropriate for the space environment.

A general effort to demonstrate industrial techniques in Earth-orbit should be emphasized to aid in the selection of such operations as candidates for space.

Planetary Environmental Engineering

The growing aspiration of all the peoples of the world to raise their standard of living portends a major unfavorable impact on the Earth's biosphere. Much of the monitoring of these initially subtle changes is available only through space activities. Control of future damage to the Earth's environment and repair that already done will be greatly enhanced by global environment information gathered from space. This enhancement may well become crucial for the preservation of the environment. How such information is to be gathered, interpreted, and disseminated needs to be much better understood. We must gain this understanding rapidly, since the problem already exists.

Ultimately, once we have learned to preserve our own biosphere and the pristine state of near planets no longer needs to be preserved, the ability to shape benign environments for human beings on other planets and moons can become a reality.

Large-Scale End-to-End Information Management

Throughout the course of the study a continuing concern has been expressed in the area of data and data management both by members of the Study Group and by others who communicate with the group.

The exponential rise in first the need, and then in the ability, to gather data through diverse space activities makes this subject of special interest to NASA. A great majority of the systems and missions utilized in the candidate space objectives harness energy and matter to facilitate the acquisition, transfer, processing, and storage of information, its eventual assimilation as new knowledge and understanding, and its use in making decisions on which subsequent actions will be based. The very large quantities of data that are projected may indeed be unique to space activities. Single Earth-orbiting spacecraft are expected to be capable of returning 10^{13} bits/day of data to information centers on Earth during the 1990s.

Demands exist for more analytical capabilities, faster response times and satisfaction of true user or experimenter needs, in turn requiring more channels, more sensors, and more complex analysis.

This data increase is implicit in all of the areas of space activities which we considered.

Future space information systems, for example, those involving meteorological, agricultural, and marine observations, will be able to benefit significantly from the miniaturization of processing and storage capabilities, from more sophisticated onboard software systems, from more economical and efficient data distribution facilities, and from advanced methods of human-machine interaction.

In all of the data-oriented activities it is important to note that it is useful information, not just data, that is required by the user. A mission that achieves the desired information with a minimum data flow has to be considered efficient and well-conceived. At the same time, a system designed to spread a "broadside" of data to hundreds of users cannot be criticized for being less than optimum in the treatment of any one of them.

Fundamental to the full exploitation of future global information systems is the development of methods whereby users can directly interact with the systems. Present space systems serve mainly as information sources to diverse communities of users who may or may not be in a position to take action on the basis of the data provided them. In the future, intervention may often be required, so that control loops between the users and the phenomena observed will have to be closed. Such feedback will surely be necessary if, for example, large-scale, responsible weather modification were to become technically feasible and economically and sociologically desirable. There would then be a need for very advanced, reliable, economical, high-capacity information systems capable of transferring information at gigabit/second rates, processing it as received or as needed, preserving it in large (10^{10} bit) memories in flight or Earth-based systems, or making it available to users in a form that enables them to make intelligent use of it on a national scale.

Other information management demands arise from those activities having the farthest outward reach, such as the detection of planets around other stars and detection of other intelligence in the galaxy. Here the primary criteria are fast search and faint electromagnetic signal detection in the presence of noise.

With the advent of highly capable flight processors, onboard processing of varying levels is a most effective form of data compression which can reduce the workload on the rest of the system. Processing can vary from merely reducing redundant transmissions to a detection system that correlates changes with previous observations and transmits only changed information to the ground. Compression ratios of 100 appear possible as was shown in Figure 26. Obviously, multi-use satellites would have to be programmed to meet specific information needs at specific times. Onboard processing also offers the possibility of onboard rectification and corrections of data to enable more direct routing of data to users.

Considerable benefits can occur through user information exchange. Marine forecasting and weather data will benefit each other. Weather and climate data will benefit crop yield system and water resource system users. Beyond sharing the same spacecraft, the next point of integration is the interconnection of national and regional data processing facilities, in particular the data archives. Provisions for user terminals in one system to access information from other user disciplines is appropriate to reduce data demands.

To provide information to users or investigators in formats they require, to archives, and to other user systems, a large and flexible information management system, engineered from source to user, appears to be needed for virtually every objective considered in the study. The capability of converting vast quantities of data into useful information to the real user is a unique challenge which requires special emphasis.

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APPENDIX A

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This appendix identifies those individuals who were involved in the study effort on a sustained basis, on a discussion basis with one or more representatives of the Study Group, or who provided inputs in some way to the effort. We have tried to make the list complete; yet in spite of all, there could be a few omissions, mistakes, etc., for which we apologize in advance.

In some cases organizations provided inputs, usually on a contractual basis; in those cases the organization is identified rather than any individual representing the organization.

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APPENDIX B
SYSTEMS

The major emphasis in the study was at the "objective" level; i.e., the identification and evaluation of space activities directed at a specific purpose (such as the prediction of climatic trends). It was necessary, however, to consider methods ("systems" in our terminology) to pursue the objectives.

We have defined a system as follows:

1000 Series – A combination of space flight missions and supporting ground based activity. A single system normally involves several flights.

2000 Series – Space flight missions only, again normally involving several flights. These systems were separated from the 1000 series because the resulting data can have a variety of uses, each requiring different ground based information support systems.

3000 Series – Ground based information support systems that are used with space flight systems of the 2000 series.

4000 Series – Ground based activities that are not used directly with space flight systems. Examples include laboratory experiments and ground based telescopes.

About 250 systems have been identified as representative ways to pursue the objectives discussed in the body of this report. Reference material on the systems is provided in Tables B-1, B-2, B-3, and B-4.

Table B-1 lists the systems we identified for each objective. Included are (a) the year of the flight, where applicable, (b) the total cost (in FY 75 dollars), (c) necessary precursor systems and events, and (d) other systems which provide comparable data for the objective. For Themes 1 through 6, the systems would be either R&D (NASA funded under the current NASA role) or operational (non-NASA funded under the current NASA role). This difference is noted in the total cost column. We have assumed that all the activities in Themes 7 through 12 would be NASA funded.

Table B-2 lists each system in each series sequentially. Included for each system are (a) whether the space portion of the system is a free flyer or manned, (b) the transportation system, (c) the number of flights and estimated years of first flight, (d) cost estimates as a function of time, the average annual cost, the peak annual cost, the total cost, and (e) our level of confidence in the cost estimate. On this last point, our definitions are as follows:

L (Low); Our confidence in the cost estimate was *low* when the technological risk was high *and* the system parameters not well defined; costs might be as much as 200% higher than the estimate given.

M (Medium); Our confidence in the cost estimate was *medium* when the technological risk was high *or* the system parameters not well defined; costs might be as much as 100% above the estimate given.

H (High); Our confidence in the cost estimate was *high* when the technological risk was low *and* the system parameters well defined; costs would not be more than 50% above the estimate given.

Table B-3 illustrates the utilization of each system for the various objectives. As we have noted in the body of the report, most of the systems contribute to several objectives.

The final table, Table B-4, provides a brief narrative description of each system.

A word of caution about the use of data in this Appendix. When schedules are shown they reflect our consideration of technical feasibility, system need, and program economics. These factors will likely change as we move forward into the 1980's and these changes will affect the schedule information included herein. System costs must similarly be used with caution. Finally, it should be recognized that there are probably alternate methods of accomplishing the objectives from those included herein; nevertheless we believe that they are representative of future space systems to accomplish the objectives discussed in Chapter 5.

Table B-1
Systems Listed by Objective

Objective 011, Global Crop Production Forecasting

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
2001	High Resolution Visible – IR System – Development	3001	1981	155			B-64	B-99
2002	High Resolution Visible – IR System – Operational	3002	1982-1986		565	2001	B-64	B-99
2003	Very High Resolution Visible – IR System – Development	3003	1988	205		2001	B-64	B-99
2004	Very High Resolution Visible – IR System – Operational	3004	1988-1996		665	2003	B-64	B-100
2005	All Weather Survey System – Development	3005	1997	265		2003	B-64	B-100
2006	All Weather Survey System – Operational	3006	1998		110	2005	B-64	B-100
2007	Long Wavelength Microwave System – Development	3003	1986	250			B-64	B-100
2008	Long Wavelength Microwave System – Operational	3004	1987-1990		215	2007	B-64	B-101
2009	High Resolution Long Wavelength Microwave System – Development	3005	1992	300		2007	B-64	B-101
2010	High Resolution Long Wavelength Microwave System – Operational	3006	1993-1998		260	2009	B-64	B-101
3001	Global Wheat Prediction System – Development	2001		42				
3002	Global Wheat Prediction System – Operational	2002			70	3001	B-68	B-105
3003	Global All Crop Prediction System – Development	2003 2007		54			B-68 B-68	B-105 B-105
3004	Global All Crop Prediction System – Operational	2004 2008			125	3003	B-68	B-105
3005	All Weather Global All Crop Prediction System – Development	2005 2009		89			B-68	B-106
3006	All Weather Global All Crop Prediction System – Operational	2006 2010			15	3005	B-68	B-106

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 012, Water Availability Forecasting

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total S*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		S Information	Description
2001	High Resolution Visible – IR System – Development	3007	1981	155		–	B-64	B-99
2002	High Resolution Visible – IR System – Operational	3008	1982-1986		565	2001	B-64	B-99
2007	Long Wavelength Microwave System – Development	3009	1986	250		–	B-64	B-100
2008	Long Wavelength Microwave System – Operational	3010	1987-1990		215	2007	B-64	B-101
2009	High Resolution Long Wavelength Microwave System – Development	3011	1992	300		2007	B-64	B-101
2010	High Resolution Long Wavelength Microwave System – Operational	3012	1993-1998		260	2009	B-64	B-101
3007	Water Resource System I – Development	2001		30		–	B-68	B-106
3008	Water Resource System I – Operational	2002			21	3007	B-68	B-106
3009	Watershed Runoff Forecast System – Development	2007		42		–	B-68	B-106
3010	Watershed Runoff Forecast System – Operational	2008			36	3009	B-68	B-106
3011	Regional Water Balance Forecast System – Development	2009		33			B-68	B-106
3012	Regional Water Balance Forecast System – Operational	2010			52	3011	B-68	B-107

Objective 013, Land Use

2001	High Resolution Visible – IR System – Development	3013	1981	155		–	B-64	B-99
2002	High Resolution Visible – IR System – Operational	3014	1982-1986		565	2001	B-64	B-99
2003	Very High Resolution Visible – IR System – Development	3015	1988	205		2001	B-64	B-99
2004	Very High Resolution Visible – IR System – Operational	3016	1988,1989 1992,1994		665	2003	B-64	B-100
2005	All Weather Survey System – Development	3017	1997	265		2003	B-64	B-100
2006	All Weather Survey System – Operational	3018	1998		110	2005	B-64	B-100
3013	Surface Cover Change Detection System – Development	2001		30		–	B-68	B-107
3014	Surface Cover Change Detection System – Operational	2002			180	3013	B-68	B-107
3015	Critical Environmental Area Monitoring System – Development	2003		40		–	B-68	B-107
3016	Critical Environmental Area Monitoring System – Operational	2004			260	3015	B-68	B-107
3017	Land Capability System – Development	2005		55		3016	B-68	B-107
3018	Land Capability System – Operational	2006			40	3017	B-68	B-108

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 014, Living Marine Resources

System		Used in** Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		S Information	Description
2007	Long Wavelength Microwave System – Development	3019	1986	250			B-64	B-100
2008	Long Wavelength Microwave System – Operational	3019	1987-1990		215	2007	B-64	B-101
2009	High Resolution Long Wavelength Microwave System – Development	3019	1992	300		2007	B-64	B-101
2010	High Resolution Long Wavelength Microwave System – Operational	3020	1993-1998		260	2009	B-64	B-101
3019	Living Marine Resources System – Development	2007 2008 2009		110			B-68	B-108
3020	Living Marine Resources System – Operational	2010			15	3019	B-68	B-108

Objective 015, Timber Inventory

2001	High Resolution Visible – IR System – Development	3021	1981	155			B-64	B-99
2002	High Resolution Visible – IR System – Operational	3022	1982-1986		565	2001	B-64	B-99
2003	Very High Resolution Visible – IR System – Development	3023	1988	205		2001	B-64	B-99
2004	Very High Resolution Visible – IR System – Operational	3024	1988,1989 1992-1994		665	2003	B-64	B-100
2005	All Weather Survey System – Development	3005 3017,3029	1997	265		2003	B-64	B-100
2006	All Weather Survey System – Operational	3006,3018 3030			110	2005	B-64	B-100
3021	Broad Area Timber Inventory System – Development	2001		15			B-68	B-108
3022	Broad Area Timber Inventory System – Operational	2002			15	3021	B-68	B-108
3023	Specific Area Timber Inventory System – Development	2003		35		3022	B-68	B-108
3024	Specific Area Timber Inventory System – Operational	2004			35	3023	B-68	B-109

*Millions, FY 75 Dollars

**Complete implementation of this Objective would also involve systems 3031-3036, 3050-3059, 1001-1006, 2011-2016, 2027-2030, 2031-2036.

Table B-1
Systems Listed by Objective

Objective 016, Range Conditions

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
2001	High Resolution Visible – IR System – Development	3025	1981	155			B-64	B-99
2002	High Resolution Visible – IR System – Operational	3026	1982-1986		565	2001	B-64	B-99
2003	Very High Resolution Visible – IR System – Development	3027	1988	205		2001	B-64	B-99
2004	Very High Resolution Visible –IR System – Operational	3028	1988,1989 1992,1994		665	2003	B-64	B-100
2005	All Weather Survey System – Development	3029	1998	265		2003	B-64	B-100
2006	All Weather Survey System – Operational	3030	1998		110	2005	B-64	B-100
3025	Range Forage Status System – Development	2001		10			B-68	B-109
3026	Range Forage Status System – Operational	2002			10	3025	B-68	B-109
3027	Range Forage Prediction System – Development	2003		15			B-69	B-109
3028	Range Forage Prediction System – Operational	2004			20	3027	B-69	B-109
3029	All Weather Range Forage System – Development	2005		30			B-69	B-109
3030	All Weather Range Forage System – Operational	2006			3	3029	B-69	B-109

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 021, Large Scale Weather Forecasting

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
2011	Weather Survey System I – Development	3031	1984	70			B-65	B-101
2012	Weather Survey System I – Operational	3032	1985,1987 1988		100	2011	B-65	B-101
2013	Passive-Active Sensors, Large Scale Weather Survey System – Development	3033	1990	100		2011	B-65	B-101
2014	Passive-Active Sensors, Large Scale Weather Survey System – Operational	3034	1991,1995 1996		250	2013	B-65	B-101
2015	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development	3035	2000	100		2013	B-65	B-102
2016	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational	3036	2001		50	2015	B-65	B-102
2031	VISSR Atmospheric Sounder System – Development	3031	1983	108			B-66	B-103
2032	VISSR Atmospheric Sounder System – Operational	3032	1984,1986 1987		180	2031	B-66	B-103
2033	Storm Satellite Survey System – Development	3033	1989	200		2031	B-66	B-103
2034	Storm Satellite Survey System – Operational	3034	1990,1994 1995		290	2033	B-67	B-104
2035	Synchronous Earth Observatory Survey System – Development	3035	1999	110		2033	B-67	B-104
2036	Synchronous Earth Observatory Survey System – Operational	3036	2000		280	2035	B-67	B-104
3031	Global Atmospheric Research Program System – Development	2011 2031		20			B-69	B-109
3032	Global Atmospheric Research Program System – Operational	2012 2032			30	3031	B-69	B-110
3033	Post-GARP System – Development	2013 2033		24			B-69	B-110
3034	Post-GARP System – Operational	2014 2034			66	3033	B-69	B-110
3035	Advanced Techniques Weather System – Development	2015 2035		20			B-69	B-110
3036	Advanced Techniques Weather System – Operational	2016 2036			10	3035	B-69	B-110

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 022, Weather Modification Experiment Support

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		S Information	Description
2011	Weather Survey System I – Development	3037	1984		70		B-65	B-101
2012	Weather Survey System I – Operational	3037	1985-1988		100		B-65	B-101
2013	Passive-Active Sensors, Large Scale Weather Survey System – Development	3037	1990		100		B-65	B-101
2014	Passive-Active Sensors, Large Scale Weather Survey System – Operational	3037	1991-1996		250		B-65	B-101
2015	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development	3037	2000		100		B-65	B-102
2016	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational	3037	2001		50	2015	B-65	B-102
2031	VISSR Atmospheric Sounder System – Development	3037	1983	90			B-66	B-103
2032	VISSR Atmospheric Sounder System – Operational	3037	1984,1986 1987		180		B-66	B-103
2033	Storm Satellite Survey System – Development	3037	1989	200				
2034	Storm Satellite Survey System – Operational	3037	1990,1994 1995		290		B-66 B-67	B-103 B-104
2035	Synchronous Earth Observatory Survey System – Development	3037	1988	110			B-67	B-104
2036	Synchronous Earth Observatory Survey System – Operational	3037	1988-1992		280		B-67	B-104
3037	Weather Modification Experiments Monitoring System	2011 2012 2013 2014 2015 2016 2031 2032 2033 2034 2035 2036		60			B-69	B-110
4004	Low Atmospheric Research				40		B-71	B-116

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 023, Climate Prediction

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
2001	High Resolution Visible – IR System – Development	3038	1981	155			B-64	B-99
2002	High Resolution Visible – IR System – Operational	3039	1982-1986		565	2001	B-64	B-99
2003	Very High Resolution Visible – IR System – Development	3038,3040	1988	205		2001	B-64	B-99
2004	Very High Resolution Visible – IR System – Operational	3039	1988-1996		665	2003	B-64	B-100
2005	All Weather Survey System – Development	3040	1997	265		2003	B-64	B-100
2006	All Weather Survey System – Operational	3041	1998		110	2005	B-64	B-100
2007	Long Wavelength Microwave System – Development	3038	1986	250			B-64	B-100
2008	Long Wavelength Microwave System – Operational	3039	1987-1990		215	2007	B-64	B-101
2009	High Resolution Long Wavelength Microwave System – Development	3040	1992	300		2007	B-64	B-101
2010	High Resolution Long Wavelength Microwave System – Operational	3041	1993-1998		260	2009	B-64	B-101
2011	Weather Survey System I – Development	3038	1984	70			B-65	B-101
2012	Weather Survey System I – Operational	3039,3040	1985-1988		100	2011	B-65	B-101
2013	Passive-Active Sensors, Large Scale Weather Survey System – Development	3038	1990	100		2011	B-65	B-101
2014	Passive-Active Sensors, Large Scale Weather Survey System – Operational	3039,3041	1991-1996		250	2011	B-65	B-101
2015	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development	3040	1986-2000	100		2013	B-65	B-102
2016	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational	3041	2001		50	2015	B-65	B-102
2017	Earth Energy Budget Monitoring System – Development	3038	1981	40			B-65	B-102
2018	Earth Energy Budget Measuring System – Operational	3039	1982-1986		150	2017	B-65	B-102
2019	Advanced Earth Energy Budget Monitoring System – Development	3040	1987	80		2017	B-65	B-102
2020	Advanced Earth Energy Budget Monitoring System – Operational	3041	1987-1998		420	2019	B-65	B-102
2021	Air Pollution Technology Satellite – Development	3038	1982	60			B-65	B-102
2022	Stratospheric Monitoring System – Development	3038	1985	60		2021	B-66	B-102

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 023, Climate Prediction (Concluded)

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		S Information	Description
2023	Stratospheric Monitoring System – Operational	3039	1986,1988 1989		100	2022	B-66	B-103
2024	Stratospheric Constituents Monitoring System – Development	3040	1991	75		2022	B-66	B-103
2025	Stratospheric Constituents Monitoring System – Operational	3041	1992,1996 1997		230	2024	B-66	B-103
2026	*Sea Survey Technology Satellite*	3038	1982	70			B-66	B-103
2027	Sea Survey System – Development	3038	1985	70		2026	B-66	B-103
2028	Sea Survey System – Operational	3039	1986-1989		210	2027	B-66	B-103
2029	High Resolution Sea Survey System – Development	3040	1991	110		2027	B-66	B-103
2030	High Resolution Sea Survey System – Operational	3041	1992-1997		250	2029	B-66	B-103
3038	Climate Parametric Systems Study – Development	(1)		65			B-69	B-110
3039	Climate Parametric Systems Study – Operational	(2)			275	3038	B-69	B-111
3040	Climate Forecasting System – Development	(3)		140		3038	B-69	B-111
3041	Climate Forecasting System – Operational	(4)			475	3040	B-69	B-111
4003	Oceanographic Research	3038,3040		30			B-71	B-116
4005	Strato/Mesosphere Research	3038,3040		60			B-71	B-116

*Millions, FY 75 Dollars

(1) 2001, 2003, 2007, 2011, 2013, 2017, 2021, 2022, 2026, 2027.
(2) 2002, 2004, 2008, 2012, 2014, 2018, 2023, 2028,
(3) 2003, 2005, 2009, 2012, 2015, 2019, 2024, 2029.
(4) 2006, 2010, 2014, 2016, 2020, 2025, 2030.

Table B-1
Systems Listed by Objective

Objective 024, Stratospheric Changes

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
2021	Air Pollution Technology Satellite – Development	3042	1982	60			B-65	B-102
2022	Stratospheric Monitoring System – Development	3043	1985	60		2021	B-66	B-102
2023	Stratospheric Monitoring System – Operational	3044	1986, 1988, 1989		100	2022	B-66	B-103
2024	Stratospheric Constituents Monitoring System – Development	3045	1991	75		2022	B-66	B-103
2025	Stratospheric Constituents Monitoring System – Operational	3046	1992, 1996, 1997		230	2024	B-66	B-103
3042	Stratospheric Parameter Experimental System – Development	2021		10			B-69	B-111
3043	Preliminary Stratospheric Prediction System – Development	2022		10		3042	B-69	B-111
3044	Preliminary Stratospheric Prediction System – Operational	2023			25	3043	B-69	B-111
3045	"3 Dimensional" Stratospheric Prediction System – Development	2024		20		3043	B-69	B-112
3046	"3 Dimensional" Stratospheric Prediction System – Operational	2025			60	3045	B-69	B-112
4005	Strato/Mesosphere Research			60			B-71	B-116

*Millions, FY 75 Dollars

Objective 025, Water Quality Monitoring**

3047	Water Quality Monitoring System – Development	Data Relay Satellite		20			B-70	B-112
3048	Water Quality Monitoring System – Operational	Data Relay Satellite			40		B-70	B-112

*Millions, FY 75 Dollars

**Remote measurements pertinent to water quality monitoring may be derived from a number of space systems, i.e., 2001-2004, 2007-2010; however, no specific remote sensing operational water quality monitoring system was defined in this study.

Table B-1
Systems Listed by Objective

Objective 026, Global Marine Weather Forecasting

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
2026	Sea Survey Technology Satellite	3049	1982	70			B-66	B-103
2027	Sea Survey System – Development	3050	1985	70		2026	B-66	B-103
2028	Sea Survey System – Operational	3051	1986,1989		210	2027	B-66	B-103
2029	High Resolution Sea Survey System – Development	3052	1991	110		2027	B-66	B-103
2030	High Resolution Sea Survey System – Operational	3053	1992-1997		250	2029	B-66	B-103
3049	Marine Parameter Experimental System – Development	2026		15			B-70	B-112
3050	Marine Forecasting System – Development	2027		15			B-70	B-112
3051	Marine Forecasting System – Operational	2028			40	3050	B-70	B-112
3052	Extended Parameter Marine Forecasting System – Development	2029		22		3050	B-70	B-113
3053	Extended Parameter Marine Forecasting System – Operational	2030			50	3052	B-70	B-113

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 031, Local Weather and Severe Storms

System		Used in Conjunction *with* System No.	Illus-trative *Flight* Dates	Total $*		Necessary Precursor *Systems or* Events	Page Numbers for Reference	
No.	Name			R&D	OPS		S Information	Description
2011	Weather Survey System I – Development	3054	1985,1987, 1988	70			B-65	B-101
2012	Weather Survey System I – Operational	3055	1990		100	2011	B-65	B-101
2013	Passive-Active Sensors, Large Scale Weather Survey System – Development	3056	1991,1995, 1996	100		2011	B-65	B-101
2014	Passive-Active Sensors, Large Scale Weather Survey System – Operational	3057	1990,1994, 1995		250	2013	B-65	B-101
2015	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development	3058	2001	100		2013	B-65	B-102
2016	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational	3059	1984		50	2015	B-65	B-102
2031	VISSR Atmospheric Sounder System – Development	3054	1984,1986, 1987	90			B-66	B-103
2032	VISSR Atmospheric Sounder System – Operational	3055	1990		180	2031	B-66	B-103
2033	Storm Satellite Survey System – Development			200		2031	B-66	B-104
2034	Storm Satellite Survey System – Operational	3057	1990,1994, 1995		290	2033	B-67	B-104
2035	Synchronous Earth Observatory Survey System – Development	3058	1999	110		2033	B-67	B-104
2036	Synchronous Earth Observatory Survey System – Operational	3059	1984		280	2035	B-67	B-104
3054	Cyclonic Scale Severe Weather Prediction System – Development	2031,2011		22			B-70	B-113
3055	Cyclonic Scale Severe Weather Prediction System – Operational	2032,2012			40	3054	B-70	B-113
3056	Thunderstorm Scale Severe Weather Prediction System – *Development*	2033,2013		41		3054	B-70	B-113
3057	Thunderstorm Scale Severe Weather Prediction System – Operational	2034,2014			60	3056	B-70	B-113
3058	Day-Night Severe Storm Prediction – Development	2035,2015		24		3056	B-70	B-113
3059	Day-Night Severe Storm Prediction – Operational	2036,2016			15	3058	B-70	B-113

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 032, Tropospheric Pollutants Monitoring

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
2021	Air Pollution Technology Satellite – Development	3060	1982	60			B-65	B-102
2037	Global Tropospheric Monitoring System – Development	3016	1988	130		2021	B-67	B-104
2038	Global Tropospheric Monitoring System – Operation	3062	1989-1992		140	2037	B-67	B-104
2039	Regional Tropospheric Monitoring System – Development	3063	1996	225		2037	B-67	B-104
2040	Regional Tropospheric Monitoring System – Operational	3064	1996		300	2039	B-67	B-104
3060	Tropospheric Parameter Experimental System	2021		30			B-70	B-114
3061	Global Air Pollution Analysis System – Development	2037		20		3060	B-70	B-114
3062	Global Air Pollution Analysis System – Operational	2038			70	3061	B-70	B-114
3063	Regional Air Pollution Prediction System – Development	2039		28		3061	B-70	B-114
3064	Regional Air Pollution Prediction System – Operational	2037			135	3063	B-70	B-114

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 033, Hazard Forecasting from In-Situ Measurements

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
3065	Hazard Warning System – Development	Data Relay Satellite		20			B-70	B-114
3066	Hazard Warning System – Operational	Data Relay Satellite			40		B-70	B-114
3067	Extended Hazard Warning System – Development	Data Relay Satellite		20			B-70	B-115
3068	Extended Hazard Warning System – Operational	Data Relay Satellite			40		B-70	B-115

Objective 034, Communication – Navigation

No.	Name	Used in Conjunction with System No.	Illustrative Flight Dates	R&D	OPS	Necessary Precursor Systems or Events	$ Information	Description
1001	Global Positioning and Communicating System – Development		1982	100			B-56	B-83
1002	Global Positioning and Communicating System – Operational		1983 1987,1988		300	1001	B-56	B-83
1003	Expanded Coverage Comm. Navigation System – Development		1992	150			B-56	B-83
1004	Expanded Coverage Comm. Navigation System – Operational		1998		170	1003	B-56	B-83
1005	Advanced Techniques Comm. Navigation System – Development		1999	150			B-56	B-83
1006	Advanced Techniques Comm. Navigation System – Operational		2000		60	1005	B-56	B-83

Objective 035, Earthquake Prediction

No.	Name	Used in Conjunction with System No.	Illustrative Flight Dates	R&D	OPS	Necessary Precursor Systems or Events	$ Information	Description
2041	Earthquake Prediction System – Development		1991-1992	210		4001	B-67	B-104
2042	Earthquake Prediction System – Operational		1998-1999		150	2041	B-67	B-105
4001	Earthquake Parameters – Development			150			B-71	B-116
4002	Very Long Baseline Interferometry				40		B-71	B-116

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 036, Control of Harmful Insects

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		S Information	Description
2001	High Resolution Visible – IR System – Development	3069	1981	155			B-64	B-99
2002	High Resolution Visible – IR System – Operational	3070	1982-1986		565	2001	B-64	B-99
2003	Very High Resolution Visible – IR System – Development	3069	1987	205		2001	B-64	B-99
2004	Very High Resolution Visible – IR System – Operational	3070 etc.	1988-1994		665	2003	B-64	B-100
2005	All Weather Survey System – Development		1997	265		2003	B-64	B-100
2006	All Weather Survey System – Operational		1998		110	2004	B-64	B-100
2007	Long Wavelength Microwave System – Development	3003	1986	250			B-64	B-100
2008	Long Wavelength Microwave System – Operational		1987-1990		215	2007	B-64	B-100
2009	High Resolution Long Wavelength Microwave System – Development	3005	1992	300		2007	B-64	B-101
2010	High Resolution Long Wavelength Microwave System – Operational		1993-1998		260	2009	B-64	B-101
2011	Weather Survey System I – Development		1984	70			B-65	B-101
2012	Weather Survey System I – Operational		1985-1988		100	2011	B-65	B-101
2013	Passive-Active Sensors, Large Scale Weather Survey System – Development		1990	100		2011	B-65	B-101
2014	Passive-Active Sensors, Large Scale Weather Survey System – Operational		1991-1996		250	2013	B-65	B-101
2015	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development		2000	100		2013	B-65	B-103
2016	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational		2001		50	2015	B-65	B-103
3069	Disease Vectors System – Development			50			B-70	B-115
3070	Disease Vectors System – Operational				93	3069	B-70	B-115

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 041, Solar Power Stations in Space

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
1007	Solar Power Technology			600			B-56	B-84
1008	Solar Power Space Test Activity		1982-1990	2400		1007	B-56	B-84
1009	Solar Power Prototype – Development		1993	50000		1007,1008	B-56	B-84
1010	Solar Power System – Operational		1998		10000	1009	B-56	B-84

Objective 042, Power Relay Via Satellites

1007	Solar Power Technology		1976-1985	600			B-56	B-84
1011	Power Relay Technology – Development		1983	100			B-56	B-84
1012	Power Relay Space Testing		1982-1990	1500		1011	B-56	B-84
1013	Power Relay Prototype Development	1012	1993		20000	1012	B-56	B-85

Objective 043, Hazardous Waste Disposal in Space

1014	Hazard Waste System – Development		1984	500	1130**		B-56	B-85
1015	Hazard Waste System – Operational		1985-1990		4096	1014	B-56	B-85

Objective 044, World Geological Atlas

2001	High Resolution Visible – IR System – Development	3071	1982	155			B-64	B-99
2002	High Resolution Visible – IR System – Operational	3072	1982-1986		565	2001	B-64	B-99
2003	Very High Resolution Visible – IR System – Development	3071	1988	205		2001	B-64	B-99
2004	Very High Resolution Visible – IR System – Operational	3072	1988,1989 1992-1994		665	2003	B-64	B-100
2005	All Weather Survey System – Development	3071	1997	265		2003	B-64	B-100
2006	All Weather Survey System – Operational	3072	1998		110	2005	B-64	B-100
3071	Geological Mapping System – Development	2001,2006		23			B-70	B-115
3072	Geological Mapping System – Operational	2001,2006			69		B-70	B-115

*Millions, FY 75 Dollars

**Includes Construction of Pacific Island Launch Site.

Table B-1
Systems Listed by Objective

Objective 051, Domestic Communications

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
1018	Domestic Communications System – Development		1984	150			B-57	B-85
1019	Domestic Communications System – Operational		1984-1993		600	1018	B-57	B-85
1020	Multi-Service Domestic Communications System – Development		1994	170			B-57	B-85
1021	Multi-Service Domestic Communications System – Operational		1994-1999		550	1020	B-57	B-85

Objective 052, International Communications

1022	International Communications System – Development		1986	110			B-57	B-85
1023	International Communications System – Operational		1986-1995		775	1022	B-57	B-86
1024	Multi-Service International Communications System – Development		1996	135			B-57	B-86
1025	Multi-Service International Communications System – Operational		1996-1990		385	1024	B-57	B-86

Objective 053, Personal Communications

1026	Personal Communications System – Development		1988	45			B-57	B-86
1027	Personal Communications System – Operational		1989		90	1026	B-57	B-86

Objective 061, Basic Physics and Chemistry

1028	"Short Term" Physical Chemical Research – Crew Operated		1981-1987	161			B-57	B-86
1029	"Long-Term" Physical Chemical Research – Crew Operated	1112or1113	1987-1999	285			B-57	B-86

Costs include Pro Rata space lab costs and space station module with systems 1030, 1031, 1033, and 1034.

Objective 062, Materials Science

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
1030	"Short-Term" Low-g Material Science Research – Crew Operated		1981-1987	322			B-57	B-86
1031	"Long-Term" Low-g Material Science Research – Crew Operated	1112or1113	1987-1999	585			B-57	B-87

*Millions, FY 75 Dollars

Costs include pro rata spacelab and space station module with systems 1028, 1029, 1033, and 1034.

Table B-1
Systems Listed by Objective

Objective 063, Commercial Processing

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
1032	Commercial Processing – Crew Operated	1112or1113	1987-1999		1000	1030	B-58	B-87

Assumed to be a commercial venture resulting from material science spacelab effort by NASA.
Costs include space station commercial processing module.

Objective 064, Biological Materials Research and Applications

1033	"Short-Term" Biological Materials Research – Crew Operated		1981-1987	161			B-58	B-87
1034	"Long-Term" Biological Materials Research – Crew Operated	1112or1113	1987-1999	285			B-58	B-87

Costs include pro rata spacelab and space station module with systems 1028, 1029, 1030, and 1031.

Objective 065, Effects of Gravity on Terrestrial Life

1035	Preliminary Effects of Gravity on Life – Crew Operated		1981-1987	76			B-58	B-87
1036	Effects of Gravity on Life – Crew Operated		1987-1999	159		1035	B-58	B-87

Costs include pro rata spacelab and space station costs with systems 1017-1020.

Objective 066, Living and Working in Space

1037	Human Performance in Space – Development	1067,1047 1042	1981-1987	303			B-58	B-87
1038	Human Performance in Space – Operational	1112or1113	1987-1999	585		1037	B-58	B-87

Costs include pro rata spacelab and space station costs with systems 1015, 1016, 1019, and 1020.

Objective 067, Physiology and Disease Processes

1039	Preliminary Disease Processes Research – Crew Operated	1037	1981-1987	152			B-58	B-88
1040	Disease Processes Research – Crew Operated	1038,1112 or 1113	1987-1999	305		1039	B-58	B-88

*Millions, FY 75 Dollars
Costs include pro rata spacelab and space station costs with systems 1015-1018.

Table B-1
Systems Listed by Objective

Objective 071, Earth's Magnetic Field

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
1041	Magnetic Field Change Satellite	4011	1983 1989,1995	160			B-58	B-88
1042	Magnetic Field Survey	4011	1983 1989,1995	175			B-58	B-88
1045	Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) Crew Operated	4011	1981	700			B-58	B-88
1075	Spacelab Solar Telescope Cluster		1981	320			B-60	B-93
4011	Ionosphere-Magnetosphere Coupling Analysis	1045	NA	60			B-71	B-117

*Millions, FY 75 Dollars

Objective 072, Crustal Dynamics

1043	Geodetic Satellites		1983,1988	14			B-58	B-88
1044	Gravitational Satellites		1981, 1986,1991	335			B-58	B-88
2041	Earthquake Prediction System – Development		1991-1992	210			B-67	B-104
2042	Earthquake Prediction System – Operational		1998-1999		150		B-67	B-105
4001	Earthquake Parameters – Development		1981-1983	150			B-71	B-116
4002	Very Long Baseline Interferometry			40			B-71	B-116

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 073, Ocean Interior and Dynamics

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
1043	Geodetic Satellites		1983,1988	14			B-58	B-88
1044	Gravitational Satellites		1981,1986 1991	335			B-58	B-88
1070	10,000 Kg Solar Observatories		1985,1987, 1989,1991, 1993		500 (260)		B-60	B-92
1076	Solar Monitor		1981	20			B-60	B-93
2026	Sea Survey Technology Satellite	3049	1982	70			B-66	B-103
2027	Sea Survey System – Development	3050	1985	70		2026	B-66	B-103
2028	Sea Survey System – Operational	3051	1986,1989		210	2027	B-66	B-103
2029	High Resolution Sea Survey System – Development	4003	1991	110			B-66	B-103
2030	High Resolution Sea Survey System – Operational	4003	1992-1997		250		B-66	B-103
4003	Oceanographic Research	2029,2030		30			B-71	B-116

*Millions, FY 75 Dollars
( ) Revisit Costs.

Table B-1
Systems Listed by Objective

Objective 074, Dynamics and Energetics of Lower Atmosphere

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
2011	Weather Survey System I – Development	3031	1984	70			B-65	B-101
2012	Weather Survey System I – Operational	3032	1985,1987		100	2011	B-65	B-101
2013	Passive-Active Sensors, Large Scale Weather Survey System – Development	3033	1990	100		2011	B-65	B-101
2014	Passive-Active Sensors, Large Scale Weather Survey System – Operational	3034	1991,1995 1996		250	2013	B-65	B-101
2015	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development	3035	2000	100		2013	B-65	B-102
2016	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational	4004	2001		50	2015	B-65	B-102
2031	VISSR Atmospheric Sounder System – Development	4004	1983	90			B-66	B-103
2032	VISSR Atmospheric Sounder System – Operational	4004	1984,1986 1987		180	2031	B-66	B-103
2033	Storm Satellite Survey System – Development	4004	1989	200		2031	B-66	B-104
2034	Storm Satellite Survey System – Operational	4004	1990,1994 1995		290	2033	B-67	B-104
2035	Synchronous Earth Observatory Survey System – Development	4004	1988	110		2033	B-67	B-104
2036	Synchronous Earth Observatory Survey System – Operational	4004	1988-1992		280	2035	B-67	B-104
4004	Low Atmospheric Research	1045,1046, 1076, 2011-2016, 2031-2036			40		B-71	B-116
4011	Ionosphere-Magnetosphere Coupling Analysis	1045	NA	60			B-71	B-117

*Millions, FY 75 Dollars

( ) Revisit Costs.

Table B-1
Systems Listed by Objective

Objective 075, Stratosphere/Mesosphere

System		Used in Conjunction with System No.	Illus-trative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
1045	Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) Crew Operated	4005	1981	550			B-58	B-88
1046	Atmospheric Neutral and Charged Particle Research	4005	1981,1983, 1985,1989, 1993,1998,	125 (115)			B-58	B-88
1070	10,000 Kg Solar Observatories	4005	1985,1987, 1989,1991, 1993	500 (260)		1075,76, 77	B-60	B-92
1075	Spacelab Solar Telescope Cluster	4005	1981	320			B-60	B-93
1076	Solar Monitor	4005	1981	20			B-60	B-93
1077	1600 Kg Solar Observatory	4005	1979,1981, 1983,1985, 1987,1989, 1991	70 (115)			B-60	B-93
2021	Air Pollution Technology Satellite – Development	3042	1982	60			B-65	B-102
2022	Stratospheric Monitoring System – Development	4005	1985	60			B-66	B-102
2023	Stratospheric Monitoring System – Operational	4005	1986,1988, 1989		100		B-66	B-103
2024	Stratospheric Constituents Monitoring System – Development	4005	1991	75			B-66	B-103
2025	Stratospheric Constituents Monitoring System – Operational	4005	1991,1996, 1997		230		B-66	B-103
4005	Strato/Mesosphere Research	2021,2022, 2023,2024, 2025		60			B-71	B-116
4011	Ionosphere-Magnetosphere Coupling Analysis	1045	NA	60			B-71	B-117

*Millions, FY 75 Dollars
( ) Revisit Costs.

Table B-1
Systems Listed by Objective

Objective 076, Ionosphere – Magnetosphere Coupling

System		Used in Conjunction with System No.	Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Page Numbers for Reference	
No.	Name			R&D	OPS		$ Information	Description
1041	Magnetic Field Change Satellite	4011	1983,1989 1995,2001		160		B-58	B-88
1042	Magnetic Field Survey	4011	1983,1989 1995,2001		175		B-58	B-88
1045	Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) Crew Operated	4011	1981	550	(Partial)		B-58	B-88
1046	Atmospheric Neutral and Charged Particle Research	4011	1982,1983 1985,1989 1993,1998		125 (115)		B-58	B-88
1047	Electrodynamic Explorer	4011	1980	50			B-58	B-89
1067	Interplanetary Near-Sun Probe	4011	1984		135		B-60	B-92
1070	10,000 Kg Solar Observatories	4011	1985,1987, 1989,1991, 1993		500 (260)	1075,76,77	B-60	B-92
1075	Spacelab Solar Telescope Cluster	4011	1981		320		B-60	B-93
1076	Solar Monitor	4011	1981		20		B-60	B-93
1077	1600 Kg Solar Observatory	4011	1979,1981, 1983,1985, 1987,1989, 1991		70 (115)		B-60	B-93
4011	Ionosphere-Magnetosphere Coupling Analysis	1041,1042, 1045,1046, 1047,1067, 1070,1075, 1076,1077	NA	60			B-71	B-117

*Millions, FY 75 Dollars

( ) Revisit Costs.

Table B-1
Systems Listed by Objective

Objective 081, How Did the Universe Begin?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1048	Wide Field X-Ray and Gamma Ray	1984,1989	80 (25)				B-59	B-89
1049	1m UV Telescope	1982,1984 1987,1990	100			1050,1051	B-59	B-89
1050	2.4m Space Telescope (LST)	1982,1985, 1988,1991, 1994	420 (240)			1049 (Partial) 1051	B-59	B-89
1051	5-6m Space Telescope	2005	1090		1050	1049 (Partial) 1050 (Partial)	B-59	B-89
1052	Small Submillimeter Receiver	1981	20			1073	B-59	B-89
1056	High Energy Astrophysics Spacelab Cluster	1980,1982, 1984,1986, 1988,1990	310 (225)			1057,1061	B-59	B-90
1057	Large Area Gamma-Ray Detector	1986,1990	150 (40)			1056 (Partial)	B-59	B-90
1058	Low Energy Gamma Explorers	1984,1985	80				B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060	1060 (Partial)	B-59	B-90
1060	1.2 Meter X-Ray Telescope	1982,1985	210 45			1059	B-59	B-90
1061	Heavy Cosmic Ray Detector	1984,1987, 1989	190 (70)			1056 (Partial)	B-59	B-91
1068	700 Kilogram X-Ray Monitor	1981 ea.yr	65				B-60	B-92
1073	Submillimeter Telescope	1984 1991,1996, 2001	160			1052 (Partial)	B-60	B-92
1100	400 Kg UV Telescope Free Flyer	1982 & every year	105 (65)			1050,1051	B-62	B-97
1102	Very Wide Field Optical Telescope	1982 & every year	1				B-62	B-97

*Millions, FY 75 Dollars
( ) Revisit Costs.

Table B-1
Systems Listed by Objective

Objective 082, How Do Galaxies Form and Evolve?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1051	B-59	B-89
1051	5-6m Space Telescope	2005	1090		1050	1050 (Partial)	B-59	B-89
1052	Small Submillimeter Receiver	1981	20			1073	B-59	B-89
1053	Infrared Interferometer	1985 and each year	420		1103		B-59	B-89
1054	Large Cryogenic IR Telescope	1984 and each year	200		1103		B-59	B-90
1055	Microwave LBI	1982	190 (180)				B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060	1060 (Partial)	B-59	B-90
1060	1.2 Meter X-Ray Telescope	1982,1985	210 (45)			1059	B-59	B-90
1072	Large Ambient IR Telescope	1982 & ea. yr.	170				B-60	B-92
1073	Submillimeter Telescope	1984	160			1052 (Partial)	B-60	B-92
1098	Large Scale Microwave Telescope	2000	2000				B-62	B-96
1101	Wide Field UV Survey	1981 & every ¼ yr.	125				B-62	B-97
1102	Very Wide Field Optical Telescope	1982 & every year	1				B-62	B-97
1103	Cryogenic IR Survey Satellite	1981,1984 1989	45 (40)			1054	B-62	B-97

*Millions, FY 75 Dollars
( ) Revisit Costs

Table B-1
Systems Listed by Objective

Objective 083, What Are Quasars?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1050	2.4m Space Telescope (LST)	1982,1985, 1988,1991, 1994	420 (240)			1051	B-59	B-89
1051	5-6m Space Telescope	2005	1090			1050 (Partial)	B-59	B-89
1053	Infrared Interferometer	1985 & ea. yr.	420		1103		B-59	B-89
1054	Large Cryogenic IR Telescope	1984 & ea. yr.	200		1103		B-59	B-90
1055	Microwave LBI	1982	190 (180)				B-59	B-90
1056	High Energy Astrophysics Spacelab Cluster	1980,1982, 1984,1986, 1988,1990	310 (225)			1061 (Partial)	B-59	B-90
1057	Large Area Gamma-Ray Detector	1986,1990	150 (40)			1056 (Partial)	B-59	B-90
1058	Low Energy Gamma Explorers	1984,1985	80				B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060	1060 (Partial)	B-59	B-90
1060	1.2 Meter X-Ray Telescope	1982,1985	210 (45)			1059	B-59	B-90
1061	Heavy Cosmic Ray Detector	1984,1987, 1989	190 (70)			1056 (Partial)	B-59	B-91
1063	Gravity Wave Detector	1986	95				B-60	B-91
1068	700 Kilogram X-Ray Monitor	1981	65				B-60	B-92
1072	Large Ambient IR Telescope	1982 & ea. year	170				B-60	B-92
1073	Submillimeter Telescope	1984	160			1052 (Partial)	B-60	B-92
1098	Large Scale Microwave Telescope	2000	2000				B-62	B-96

*Millions, FY 75 Dollars

( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 083, What Are Quasars? (Concluded)

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1102	Very Wide Field Optical Telescope	1982 & every yr.	1				B-62	B-97
1103	Cryogenic IR Survey Satellite	1981,1984, 1989	45 (40)			1054	B-62	B-97

*Millions, FY 75 Dollars

( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 084, Will the Universe Expand Forever?

System		Illus-trative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1048	Wide Field X-Ray and Gamma Ray	1984,1989	80 (25)				B-59	B-89
1049	1m UV Telescope	1982,1984, 1987,1990	100			1050,1051	B-59	B-89
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1049 (Partial) 1051	B-59	B-89
1051	5-6m Space Telescope	2005	1090		1050	1049 (Partial) 1050 (Partial)	B-59	B-89
1054	Large Cryogenic IR Telescope	1984 & each year			1103	1103 (Partial)	B-59	B-90
1056	High Energy Astrophysics Spacelab Cluster	1980,1982, 1984,1986, 1990	310 (225)			1057 (Partial) 1061 (Partial)	B-59	B-90
1057	Large Area Gamma-Ray Detector	1986,1990	150 (40)			1056 (Partial)	B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060	1060 (Partial)	B-59	B-90
1060	1.2 Meter X-Ray Telescope	1982,1985	210 (45)			1059	B-59	B-90
1061	Heavy Cosmic Ray Detector	1984,1987, 1989	190 (70)			1056 (Partial)	B-59	B-91
1072	Large Ambient IR Telescope	1982 & each year	170			1052 (Partial)	B-60	B-92
1100	400 Kg UV Telescope Free Flyer	1981,1986, 1991,1996, 2001	105 (65)			1050,1051	B-62	B-97
1102	Very Wide Field Optical Telescope	1982 & every year	1				B-62	B-97

*Millions, FY 75 Dollars

( ) Revisit Costs.

Table B-1
Systems Listed by Objective

Objective 085, What is the Nature of Gravity?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			S Information	Description
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1051	B-59	B-89
1051	5-6m Space Telescope	2000	1090		1050	1050 (Partial)	B-59	B-89
1062	Relativity Experiments in Earth Orbit with Freely Spinning Gyroscope	1983	100				B-59	B-91
1063	Gravity Wave Detector	1986	95				B-60	B-91
1064	EOTVOS Effect Experiment	1983	75				B-60	B-91
1065	Stable Clock/Gyro in Solar Orbit	1992	300		1062	1062 (Partial)	B-60	B-91
1066	Mercury Orbiter (W/Penetrometers)	1985	265			1067 (Partial) 1094 (Partial)	B-60	B-91
1067	Interplanetary Near-Sun Probe	1984	135			1066	B-60	B-92

*Millions, FY 75 Dollars
( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 091, Nature of Stellar Explosions

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			S Information	Description
1048	Wide Field X-Ray and Gamma Ray	1984,1989	80 (25)			1057	B-59	B-89
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1051	B-59	B-89
1051	5-6m Space Telescope	2000	1090		1050	1050 (Partial)	B-59	B-89
1055	Microwave LBI	1982,1984, 1986,1988, 1990,1992	190 (180)				B-59	B-90
1056	High Energy Astrophysics Spacelab Cluster	1980,1982 1984,1986 1988, 1990	310 (225)			1057 (Partial) 1061 (Partial) 1048 (Partial)	B-59	B-90
1057	Large Area Gamma-Ray Detector	1986,1990	150 (40)			1056 (Partial)	B-59	B-90
1058	Low Energy Gamma Explorers	1984,1985	80				B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060	1060 (Partial)	B-59	B-90
1060	1.2 Meter X-Ray Telescope	1982,1985	210 (45)			1059	B-59	B-90
1061	Heavy Cosmic Ray Detector	1984,1987, 1989	190 (70)			1056 (Partial)	B-59	B-91
1063	Gravity Wave Detector	1986	95				B-60	B-91
1068	700 Kilogram X-Ray Monitor	1981	65				B-60	B-92
1069	Solar System Escape Spacecraft	1980	225				B-60	B-92
1074	Low Frequencies LBI	1987	310				B-60	B-93
1098	Large Scale Microwave Telescope	2000	2000				B-62	B-96

*Millions, FY 75 Dollars
( ) Revisit costs

Table B-1
Systems Listed by Objective

Objective 092, The Nature of Black Holes?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1049	1m UV Telescope	1982,1984, 1989,1990	100			1050,1051, 1100 (Partial)	B-59	B-89
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1051 1049 (Partial)	B-59	B-89
1051	5-6m Space Telescope	2000	1090		1050	1050 (Partial)	B-59	B-89
1053	Infrared Interferometer	1985 & ea. year	420		1103		B-59	B-89
1054	Large Cryogenic IR Telescope	1985 & ea. year	200		1103		B-59	B-90
1055	Microwave LBI	1982,1984, 1986,1988, 1990,1992	190 (180)				B-59	B-90
1056	High Energy Astrophysics Spacelab Cluster	1980,1982, 1984,1986, 1988,1990	310 (225)			1057 (Partial), 1061 (Partial)	B-59	B-90
1057	Large Area Gamma-Ray Detector	1986,1990	150 (40)			1056 (Partial)	B-59	B-90
1058	Low Energy Gamma Explorers	1984,1985	80				B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060	1060 (Partial)	B-59	B-90
1060	1.2 Meter X-Ray Telescope	1982,1985	210 (45)			1059	B-59	B-90
1061	Heavy Cosmic Ray Detector	1984,1987, 1989	190 (70)			1056 (Partial)	B-59	B-91
1063	Gravity Wave Detector	1986	95				B-60	B-91
1068	700 Kilogram X-Ray Monitor	1981 ea. year	65				B-60	B-92
1074	Low Frequencies LBI	1987	310				B-60	B-92
1099	200-1000 A UV Telescope	1984	170				B-62	B-96

*Millions, FY 75 Dollars
(   ) Revisit Costs

Table B-1
Systems Listed by Objective

Objective 092, The Nature of Black Holes? (Concluded)

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1100	400 Kg UV Telescope Free Flyer	1981,1986, 1991,1996, 2001	105 (65)			1049 (Partial) 1050, 1051	B-62	B-97

*Millions, FY 75 Dollars
( ) Revisit Costs

Table B-1
Systems Listed by Objective

Objective 093, Where and How are Elements Formed?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1049	1m UV Telescope	1982,1984 1987,1990	100		1050	1051 1100 (Partial)	B-59	B-89
1050	2.4m Space Telescope	1982,1985 1988,1991 1994	420 (240)			1051 1049 (Partial)	B-59	B-89
1051	5-6m Space Telescope	2005	1090		1050	1050 (Partial)	B-59	B-89
1056	High Energy Astrophysics Space Lab Cluster	1980,1982 1984,1986 1988,1990	310 (225)			1057 (Partial) 1061 (Partial)	B-59	B-90
1057	Large Area Gamma-Ray Detector	1986,1990	150 (40)			1056 (Partial)	B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060		B-59	B-90
1061	Heavy Cosmic Ray Detector	1984,1987 1989	190 (70)			1056 (Partial)	B-59	B-91
1069	Solar System Escape Spacecraft	1980	225				B-60	B-92
1070	10,000 Kg Solar Observatories	1985,1987 1989,1991 1993	500 (260)			1075 (Partial) 1077 (Partial)	B-60	B-92
1072	Large Ambient IR Telescope	1982 & ea. year	170				B-60	B-92
1075	Space Lab Solar Telescope Cluster	1981	320			1070 (Partial)	B-60	B-93
1077	1600 Kg Solar Observatory	1979,1981 1983,1985 1987,1989 1991	70 (115)			1075 (Partial) 1070	B-60	B-93
1085	Asteroid Sample Return	1997	650				B-61	B-94
1086	Comet Sample Return	2000	750				B-61	B-94
1099	200-1000 A UV Telescope	1984	170				B-62	B-96

*Millions, FY 75 Dollars

( ) Revisit Costs.

Table B-1
Systems Listed by Objective

Objective 093, Where and How are Elements Formed? (Concluded)

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1100	400 Kg UV Telescope Free Flyer	1981,1986, 1991,1996, 2001	105 (65)			1049 (Partial) 1050, 1051	B-62	B-97

*Millions, FY 75 Dollars
( ) Revisit Costs

Table B-1
Systems Listed by Objective

Objective 094, What is the Nature of Cosmic Rays?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1048	Wide Field X-Ray and Gamma Ray	1984,1989	80 (25)				B-59	B-89
1049	1m UV Telescope	1982,1984 1981,1990	100			1050,1051	B-59	B-89
1050	2.4m Space Telescope	1982,1985 1988,1991 1994	420 (240)			1049 (Partial) 1051	B-59	B-89
1051	5-6m Space Telescope	2000	1090		1050	1050 (Partial)	B-59	B-89
1056	High Energy Astrophysics Space Lab Cluster	1980,1982 1984,1986 1988,1990	310 (225)			1057 (Partial) 1061 (Partial)	B-59	B-90
1057	Large Area Gamma-Ray Detector	1986,1990	150 (40)			1056 (Partial)	B-59	B-90
1058	Low Energy Gamma Explorers	1984,1985	80			1056 (Partial)	B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060			
1061	Heavy Cosmic Ray Detector	1984,1987 1989	190 (70)			1056 (Partial)	B-59	B-91
1067	Interplanetary Near-Sun Probe	1984	135			1071	B-60	B-92
1069	Solar System Escape Spacecraft	1980	225			1071 (Partial)	B-60	B-92
1070	10.000 Kg Solar Observatories	1985	500 (260)			1077 (Partial) 1075 (Partial)	B-60	B-92
1071	Observatory in Solar Polar Orbit	1983	200			1067	B-60	B-92
1075	Space Lab Solar Telescope Cluster	1981	320			1077 (Partial) 1070 (Partial)	B-60	B-93
1077	1600 Kg Solar Observatory	1979,1981 1983,1985 1987,1989	70 (115)			1075,1070	B-60	B-93
1085	Asteroid Sample Return	1997	650			1089	B-61	B-94
1089	Lunar Sample Return (Highlands)	1988	670			1085	B-61	B-95

*Millions, FY 75 Dollars

( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 101, What Are the Composition and Dynamics of Interstellar Matter?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1048	Wide Field X-Ray and Gamma Ray	1984,1989	80 (25)			1100 (Partial)	B-59	B-89
1049	1m UV Telescope	1982,1984 1987,1990	100				B-59	B-89
1050	2.4m Space Telescope	1982,1985 1988,1991 1984	40 (240)			1051 1049 (Partial)	B-59	B-89
1051	5-6m Space Telescope	2005	1090		1050	1050 (Partial)	B-59	B-89
1053	Infrared Interferometer	1985 and each year	420		1103		B-59	B-89
1054	Large Cryogenic IR Telescope	1984 and each year	200		1103		B-59	B-90
1055	Microwave LBI	1982,1984, 1986,1988, 1990,1992	190 (180)			1098 (Partial) 1073 (Partial)	B-59	B-90
		1984,1988, 1990	(225)			1061 (Partial)		
1057	Large Area Gamma-Ray Detector	1986,1990	150 (40)				B-59	B-90
1058	Low Energy Gamma Explorers	1984,1985	80				B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060	1060 (Partial)	B-59	B-90
1060	1.2 Meter X-Ray Telescope	1982,1985	210 (45)			1059	B-59	B-90
1061	Heavy Cosmic Ray Detector	1984,1987, 1989	190 (70)				B-59	B-91
1068	700 Kilogram X-Ray Monitor	1981	65				B-60	B-92
1069	Solar System Escape Spacecraft	1980	225				B-60	B-92

*Millions, FY 75 Dollars
( ) Revisit costs

Table B-1
Systems Listed by Objective

Objective 101, What Are the Composition and Dynamics of Interstellar Matter? (Concluded)

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1072	Large Ambient IR Telescope	1982 and each year	170			1073 (Partial)	B-60	B-92
1073	Submillimeter Telescope	1984	160		1052	1072 (Partial)	B-60	B-92
1074	Low Frequencies LBI	1987	310				B-60	B-93
1086	Comet Sample Return	2000	750			1111 (Partial)	B-61	B-94
1098	Large Scale Microwave Telescope	2000	2000			1055	B-62	B-96
1099	200-1000 A UV Telescope	1984	170				B-62	B-96
1100	400 Kg UV Telescope Free Flyer	1981,1986 1991,1996 2001	105 (65)			1049,1050	B-62	B-97
1101	Wide Field UV Survey	1981 & every ¼ year	125				B-62	B-97
1102	Very Wide Field Optical Telescope	1982 & every year	1				B-62	B-97
1103	Cryogenic IR Survey Satellite	1981,1984 1989	45 (40)			1054	B-62	B-97
1111	Comet Rendezvous	1981	210			1086	B-63	B-98

*Millions, FY 75 Dollars

( ) Revisit costs

Table B-1
Systems Listed by Objective

Objective 102, Why and How Does Interstellar Dust Condense into Stars and Planets?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1051	5-6 m Space Telescope	2000	1090		1050		B-59	B-89
1053	Infrared Interferometer	1985 and each year	420		1103		B-59	B-89
1054	Large Cryogenic IR Telescope	1984 and each year	200		1103		B-59	B-90
1055	Microwave LBI	1982	190 (180)				B-59	B-90
1072	Large Ambient IR Telescope	1982 and each year	170			1073 (Partial)	B-60	B-92
1073	Submillimeter Telescope	1984	160			1072 (Partial)	B-60	B-92
1078	Mercury Sample Return	1999	2500				B-61	B-93
1098	Large Scale Microwave Telescope	2000	2000				B-62	B-96
1103	Cryogenic IR Survey Satellite	1981,1984, 1989	45 (40)			1053,1054	B-62	B-97

*Millions, FY 75 Dollars
( ) Revisit costs

Table B-1
Systems Listed by Objective

Objective 103, Nature and Cause of Solar Activity

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1049	1m UV Telescope	1982,1984, 1987,1990	100			1100 (Partial) 1050,1051	B-59	B-89
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1051 1049 (Partial)	B-59	B-89
1051	5-6 m Space Telescope	2000	1090		1050	1050 (Partial) 1049 (Partial)	B-59	B-89
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060	1060	B-59	B-90
1067	Interplanetary Near-Sun Probe	1984	135				B-60	B-92
1070	10,000 Kg Solar Observatories	1985	500 (260)			1071 (Partial) 1077 (Partial) 1075 (Partial)	B-60	B-92
1071	Observatory in Solar Polar Orbit	1983	200				B-60	B-92
1073	Submillimeter Telescope	1984	160				B-60	B-92
1075	Spacelab Solar Telescope Cluster	1981	320			1070 (Partial)	B-60	
1076	Solar Monitor		20				B-60	B-93
1077	1600 Kg Solar Observatory	1979	70 (115)			1070 1075 (Partial)	B-61	B-93
1078	Mercury Sample Return	1999	2500			1089 (Partial)	B-61	B-93
1089	Lunar Sample Return (Highlands)	1988	670			1078	B-61	B-95
1100	400 Kg UV Telescope Free Flyer	1981,1986, 1991,1996, 2001	105 (65)			1049,1050	B-62	B-97

*Millions, FY 75 Dollars
( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 104, Corona and Interplanetary Matter

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1045	Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) Crew Operated	1981,1982 1984	550				B-59	B-89
1047	Electrodynamic Explorer	1980	50				B-59	B-89
1049	1m UV Telescope	1982,1984 1987,1990	100			1050, 1100 (Partial)	B-59	B-89
1050	2.4m Space Telescope	1982,1985 1988,1991 1994	420 (240)			1051, 1049 (Partial)	B-59	B-89
1051	5-6m Space Telescope	2000	1090		1050	1050 (Partial) 1049 (Partial)	B-59	B-89
1066	Mercury Orbiter (W/Penetrometers)	1985	265				B-60	B-91
1067	Interplanetary Near-Sun Probe	1984	135			1071 (Partial)	B-60	B-92
1069	Solar System Escape Spacecraft	1980	225				B-60	B-92
1070	10,000 Kg Solar Observatories	1985	500 (260)			1077 (Partial) 1075 (Partial)	B-60	B-92
1071	Observatory in Solar Polar Orbit	1985	200			1067 (Partial)	B-60	B-92
1074	Low Frequencies LBI	1987	310				B-60	B-93
1075	Space Lab Solar Telescope Cluster	1981	320			1070 (Partial)	B-60	B-93
1076	Solar Monitor	1981	20				B-60	B-93
1077	1600 Kg Solar Observatory	1979	70 (115)			1070	B-60	B-93
1099	200-1000 A UV Telescope	1984	170				B-62	B-96
1100	400 Kg UV Telescope Free Flyer	1981,1986 1991,1996, 2001	105 (65)			1049,1050	B-62	B-97

*Millions, FY 75 Dollars
( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 105, What is the Ultimate Fate of the Sun? (Concluded)

System No.	System Name	Illustrative Flight Dates	Total $* R&D	Total $* OPS	Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference: $ Information	Page Numbers for Reference: Description
1047	Electrodynamic Explorer	1980	50				B-59	B-89
1049	1m UV Telescope	1982,1984, 1987,1990	100			1050,1051 1100 (Partial)	B-59	B-89
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1049 (Partial) 1051 1100 (Partial)	B-59	B-89
1051	5-6 m Space Telescope	2005	1090		1050	1049 (Partial) 1050 (Partial)	B-59	B-89
1054	Large Cryogenic IR Telescope	1984 and each year	200		1103		B-59	B-90
1059	Large X-Ray Telescope	1990,1995	370 (65)		1060	1060 (Partial)	B-59	B-90
1060	1.2 Meter X-Ray Telescope	1982,1985	210 (45)			1059	B-59	B-90
1061	Heavy Cosmic Ray Detector	1984,1987 1989	190 (170)				B-59	B-91
1070	10,000 Kg Solar Observatories	1985,1987, 1989,1991, 1993	500 (260)			1077 (Partial)	B-60	B-92
1071	Observatory in Solar Polar Orbit	1983	200				B-60	B-92
1072	Large Ambient IR Telescope	1982 and each year	170				B-60	B-92
1076	Solar Monitor	1981	20				B-60	B-93
1077	1600 Kg Solar Observatory	1979	70 (115)			1070 (Partial)	B-60	B-93
1099	200-1000 A UV Telescope	1984	170				B-62	B-96
1100	400 Kg UV Telescope Free Flyer	1981,1986, 1991,1996, 2001	105 (65)			1049,1050	B-62	B-97
1103	Cryogenic IR Survey Satellite	1981,1984, 1989	45 (40)			1054	B-62	B-97

*Millions, FY 75 Dollars

( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 111, What Processes Occurred During Formation of the Solar System?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other** Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1051	5-6 m Space Telescope	2000	1090		1050		B-59	B-89
1054	Large Cryogenic IR Telescope	1984 and each year	200		1103		B-59	B-90
1066	Mercury Orbiter (W/Penetrometers)	1985	265		1104		B-60	B-91
1072	Large Ambient IR Telescope	1982 and each year	170				B-60	B-92
1078	Mercury Sample Return	1999	2500		1066,1080	1066	B-61	B-93
1079	Venus Surface Sample Return	1994	2300		1088,1080	1087,1088	B-61	B-93
1080	Mars Surface Sample Return	1988	1700		1090	1090,1095	B-61	B-94
1081	Jupiter Atmospheric Probes	1980	205		Venus Probes	1091	B-61	B-94
1082	Saturn Atmospheric Probes	1984	175		Venus Probes	1096	B-61	B-94
1083	Titan Orbiter W/Penetrometer	1991	300		1090,1107		B-61	B-94
1084	Uranus Atmospheric Probe	1984	235		Venus Probes	1093	B-61	B-94
1085	Asteroid Sample Return	1997	650		1094	1094	B-61	B-94
1086	Comet Sample Return	2000	750			1110,1111	B-61	B-94
1087	Venus Orbiter Imaging Radar W/Penetrometers	1989	225		Venus Probe 1090		B-61	B-95
1088	Venus Lander	1985	700		Venus Probe	1087	B-61	B-95
1089	Lunar Sample Return (Highlands)	1988	670		1104	1104,1105, 1106	B-61	B-95
1090	Mars Polar Orbiter (W/Penetrometers)	1981	170		1104		B-61	B-95
1091	Jupiter Orbiters Spinning/3 Axis	1985	180			1107	B-61	B-95
1092	Titan Lander	2000	800		1083	1083	B-61	B-95

*Millions, FY 75 Dollars
**"Partial" for all systems listed.

Table B-1
Systems Listed by Objective

Objective 111, What Processes Occurred During Formation of the Solar System? (Concluded)

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other** Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1093	Uranus Orbiter	1995	350		1091	1108	B-62	B-95
1094	Asteroid Rendezvous W/Penetrometer Plus Laser	1987	260				B-62	B-96
1095	Mars Lander/Rover	1985	630		1090	1090	B-62	B-96
1096	Saturn Orbiter	1986	300		1091	1107	B-62	B-96
1097	Neptune Orbiter	2000	450		1091	1109	B-62	B-96
1103	Cryogenic IR Survey Satellite	1981,1984, 1989	45 (40)				B-62	B-97
1104	Lunar Polar Orbiter	1980	100				B-62	B-97
1105	Lunar Orbiter W/Penetrometers	1983	180				B-62	B-97
1106	Lunar Rover Unmanned	1988	550		1104	1104,1105	B-62	B-97
1107	Jupiter-Saturn Flyby	1977	350				B-62	B-98
1108	Uranus Flyby	1979	180				B-63	B-98
1109	Neptune Flyby	1992	225				B-63	B-98
1110	Comet Flyby/Fly-Through	1980	90				B-63	B-98
1111	Comet Rendezvous	1981	210			1110	B-63	B-98
1115	12 Person Lunar Base		10600		1104	1089,1104 1105,1106	B-63	B-99
1116	Crew Operated Flight To Mars		32000			1080,1090 1095	B-63	B-99
4007	Earth Fossil and Rock Analysis						B-71	B-117
4008	Lunar Sample Analysis						B-71	B-117
4009	Returned Solar System Sample Analysis				1080		B-71	B-117

*Millions, FY 75 Dollars

( ) Revisit costs.

**"Partial" for all systems listed.

Table B-1
Systems Listed by Objective

Objective 112, How Do Planets, Large Satellites and Atmospheres Evolve?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other** Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1045	Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) Crew Operated	1981,1982, 1984,1985	550				B-58	B-88
1046	Atmospheric Neutral and Charged Particle Research	1981,1983, 1985,1989, 1998,1998	125 (115)				B-58	B-88
1047	Electrodynamic Explorer	1980	50				B-58	B-89
1049	1m UV Telescope	1982,1984, 1987,1990	100		1050,1051		B-59	B-89
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1049	B-59	B-89
1051	5-6m Space Telescope	2000	1090		1050	1050 (Partial)	B-59	B-89
1054	Large Cryogenic IR Telescope	1984 and each year	200		1103	1049 (Partial)	B-59	B-90
1066	Mercury Orbiter (W/Penetrometers)	1985	265		1104		B-60	B-91
1067	Interplanetary Near-Sun Probe	1984	135				B-60	B-92
1072	Large Ambient IR Telescope	1982 and each year	170				B-60	B-92
1078	Mercury Sample Return	1999	2500		1066,1080	1066	B-61	B-93
1079	Venus Surface Sample Return	1994	2300		1088,1080	1087,1088	B-61	B-93
1080	Mars Surface Sample Return	1988	1700		1090	1090,1095	B-61	B-94
1081	Jupiter Atmospheric Probes	1980	205		Venus Probes	1091	B-61	B-94
1082	Saturn Atmospheric Probes	1984	175		Venus Probes	1096	B-61	B-94
1083	Titan Orbiter W/Penetrometer	1996	300		1090,1107		B-61	B-94
1084	Uranus Atmospheric Probe	1984	235		Venus Probes	1093	B-61	B-94
1085	Asteroid Sample Return	1997	650		1094	1094	B-61	B-94
1086	Comet Sample Return	2000	750			1010,1011	B-61	B-94

*Millions, FY 75 Dollars

( ) Revisit costs.

**"Partial" for all systems listed.

Table B-1
Systems Listed by Objective

Objective 112, How Do Planets, Large Satellites and Atmospheres Evolve? (Continued)

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other** Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1087	Venus Orbiter Imaging Radar W/Penetrometers	1983	225		1090 Venus Probe		B-61	B-95
1088	Venus Lander	1985	700		Venus Probes	1087	B-61	B-95
1089	Lunar Sample Return (Highlands)	1988	670			1104,1105 1106	B-61	B-95
1090	Mars Polar Orbiter (W/Penetrometers)	1986	170		1104		B-61	B-95
1091	Jupiter Orbiters Spinning/3 Axis	1981	180			1107	B-61	B-95
1092	Titan Lander	2000	830		1083	1083	B-61	B-95
1093	Uranus Orbiter	1995	350			1108	B-61	B-95
1094	Asteroid Rendezvous W/Penetrometer Plus Laser	1987	260				B-62	B-96
1095	Mars Lander/Rover	1986	630		1090	1090	B-62	B-96
1096	Saturn Orbiter	1986	300		1091	1107	B-62	B-96
1097	Neptune Orbiter	2000	450		1091	1109	B-62	B-96
1100	400 Kg UV Telescope Free Flyer	1981,1986, 1991,1996, 2001	105 (65)			1049,1050, 1051	B-62	B-97
1104	Lunar Polar Orbiter	1980	100				B-62	B-97
1105	Lunar Orbiter W/Penetrometers	1983	180				B-62	B-97
1106	Lunar Rover Unmanned	1988	550		1104	1104,1105	B-62	B-97
1107	Jupiter-Saturn Flyby	1977	350				B-62	B-98
1108	Uranus Flyby	1979	180				B-63	B-98
1109	Neptune Flyby	1992	225				B-63	B-98
1110	Comet Flyby/Fly-Through	1980	90				B-63	B-98
1111	Comet Rendezvous	1981	210			1110	B-63	B-99
1115	12 Person Lunar Base		10600		1104	1089,1104, 1105,1106		

*Millions, FY 75 Dollars

( ) Revisit costs.

**"Partial" for all systems listed.

Table B-1
Systems Listed by Objective

Objective 112, How Do Planets, Large Satellites and Atmospheres Evolve? (Concluded)

System		Illustrative Flight Dates	Total $*		Necessary *Precursor* Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1116	Crew Operated Flight To Mars		32000			1080,1090 1095 (Partial)	B-63	B-99
4005	Strato/Mesosphere Research		60				B-71	B-116
4007	Earth Fossil and Rock Analysis						B-71	B-117
4008	Lunar Sample Analysis						B-71	B-117
4009	Returned Solar System Sample Analysis				1080		B-71	B-117

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 113, How Can Atmospheric Dynamics Be Quantified?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1045	Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) Crew Operated	1981,1982, 1984	550				B-59	B-88
1046	Atmospheric Neutral and Charged Particle Research	1981,1983, 1985,1989, 1993,1998	125 (115)				B-59	B-88
1049	1m UV Telescope	1982,1984, 1987,1990	100			1050,1051	B-59	B-89
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1049,1051	B-59	B-89
1051	5-6m Space Telescope	2005	1090		1050	1050 (Partial) 1049 (Partial)	B-59	B-89
1070	10,000 Kg Solar Observatories	1985,1987, 1989,1991, 1993	500 (260)			1077	B-60	B-92
1072	Large Ambient IR Telescope	1982 and each year	170				B-60	B-92
1076	Solar Monitor	1981	20				B-60	B-93
1077	1600 Kg Solar Observatory	1979,1981, 1983,1985, 1987,1989, 1991	70 (115)			1070	B-60	B-93
1081	Jupiter Atmospheric Probes	1980	205		Venus Probes	1091 (Partial)	B-61	B-94
1082	Saturn Atmospheric Probes	1984	175		Venus Probes	1096 (Partial)	B-61	B-94
1083	Titan Orbiter W/Penetrometer	1996	300		1090,1107		B-61	B-94
1084	Uranus Atmospheric Probe	1984	235		Venus Probe	1093 (Partial)	B-61	B-94
1087	Venus Orbiter Imaging Radar W/Penetrometers	1983	225		Venus Probe, 1090		B-61	B-95
1088	Venus Lander	1985	700		Venus Probe	1087 (Partial)	B-61	B-95

*Millions, FY 75 Dollars

( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 113, How Can Atmospheric Dynamics Be Quantified? (Concluded)

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1090	Mars Polar Orbiter (W/Penetrometers)	1986	170		1104		B-61	B-95
1091	Jupiter Orbiters Spinning/3 Axis	1981	180				B-61	B-95
1092	Titan Lander	2000	800		1083	1083 (Partial)	B-61	B-95
1093	Uranus Orbiter	1995	350		1091		B-61	B-95
1095	Mars Lander/Rover	1984	630		1090		B-62	B-96
1096	Saturn Orbiter	1986	300		1091		B-62	B-96
1097	Neptune Orbiter	2010	450		Venus Probe 1091		B-62	B-96
1100	400 Kg UV Telescope Free Flyer	1981,1986, 1991,1996, 2006	105 (65)			1049,1050, 1051	B-62	B-97
1107	Jupiter-Saturn Flyby	1977	350				B-62	B-98
1108	Uranus Flyby	1979	180				B-63	B-98
1109	Neptune Flyby	1992	225				B-63	B-98
1116	Crew Operated Flight To Mars		32000			1090,1095	B-63	B-99
2019	Advanced Earth Energy Budget Monitoring System – Development						B-65	B-102
4003	Oceanographic Research		30				B-71	B-116
4004	Low Atmospheric Research		40				B-71	B-116
4005	Strato/Mesosphere Research		60				B-71	B-116

*Millions, FY 75 Dollars
( ) Revisit costs

Table B-1
Systems Listed by Objectives

Objective 114, What is the Origin and History of Magnetic Fields?

System		Illus-trative Flight Dates	Total S*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			S Information	Description
1041	Magnetic Field Change Satellite	1983.1989, 1995.2001	160				B-58	B-88
1042	Magnetic Field Survey	1983.1989. 1995.2001	175				B-58	B-88
1045	Atmospheric. Magnetospheric. and Plasmas in Space (AMPS) Crew Operated	1981,1982, 1984	550				B-58	B-88
1047	Electrodynamic Explorer	1979	50				B-58	B-89
1066	Mercury Orbiter (W/Penetrometers)	1985	265		1104		B-60	B-91
1067	Interplanetary Near-Sun Probe	1984	135				B-60	B-92
1070	10,000 Kg Solar Observatories	1985,1987, 1989,1991, 1993	500 (260)			1075 (Partial)	B-60	B-92
1071	Observatory in Solar Polar Orbit	1983	200				B-60	B-92
1074	Low Frequencies LBI	1987	310				B-60	B-93
1075	Spacelab Solar Telescope Cluster	1981	320			1070 (Partial)	B-60	B-93
1078	Mercury Sample Return	1999	2500		1066,1080		B-61	B-93
1079	Venus Surface Sample Return	1994	2300		1088,1080		B-61	B-93
1080	Mars Surface Sample Return	1988	1700		1090		B-61	B-94
1081	Jupiter Atmospheric Probes	1980	205		Venus probe		B-61	B-94
1082	Saturn Atmospheric Probes	1984	175		Venus probe		B-61	B-94
1083	Titan Orbiter W/Penetrometer	1996	300		1090,1107	1092 (Partial)	B-61	B-94
1087	Venus Orbiter Imaging Radar W/Penetrometers	1989	225		1090 Venus probe		B-61	B-95
1089	Lunar Sample Return (Highlands)	1988	670				B-61	B-95
1090	Mars Polar Orbiter (W/Penetrometers)	1981	170		1104	1095 (Partial)	B-61	B-95
1091	Jupiter Orbiters Spinning/3 Axis	1981	180		1093,1096, 1097	1081 (Partial) 1107 (Partial)	B-61	B-95

*Millions, FY 75 Dollars

( ) Revisit costs.

Table B-1
Systems Listed by Objectives

Objective 114, What is the Origin and History of Magnetic Fields? (Concluded)

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other** Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1092	Titan Lander	2000	800		1083		B-61	B-95
1093	Uranus Orbiter	1995	350		1091	1084,1108	B-61	B-95
1094	Asteroid Rendezvous W/Penetrometer Plus Laser	1987	260				B-62	B-96
1095	Mars Lander/Rover	1985	630		1090		B-62	B-96
1096	Saturn Orbiter	1986	300		1091	1082,1107	B-62	B-96
1097	Neptune Orbiter	2000	450		1091	1109	B-62	B-96
1104	Lunar Polar Orbiter		100			1106	B-62	B-97
1106	Lunar Rover Unmanned		550		1104		B-62	B-97
1107	Jupiter-Saturn Flyby		350				B-62	B-98
1108	Uranus Flyby		180				B-63	B-98
1109	Neptune Flyby		225				B-63	B-98
1115	12 Person Lunar Base		10600		1104	108,1104, 1106	B-63	B-99
1116	Crew Operated Flight To Mars		32000			1080,1090, 1095	B-63	B-99
4007	Earth Fossil and Rock Analysis						B-71	B-117
4008	Lunar Sample Analysis						B-71	B-117
4009	Returned Solar System Sample Analysis				1080		B-71	B-117

*Millions, FY 75 Dollars
( ) Revisit costs
**"Partial" for all systems listed.

Table B-1
Systems Listed by Objective

Objective 121, How Did Life On Earth Originate?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1080	Mars Surface Sample Return	1988	1700		Viking, 1090		B-61	B-94
1086	Comet Sample Return	2000	750		1111		B-61	B-94
1092	Titan Lander	2000	635		Viking		B-61	B-95
1095	Mars Lander/Rover	1985	630		Viking	1080 (Partial)	B-62	B-96
1115	12 Person Lunar Base		10600				B-63	B-99
1116	Crew Operated Flight To Mars		32000				B-63	B-99
4006	Synthesis of Living Matter in Labs		30				B-71	B-116
4007	Earth Fossil and Rock Analysis		60				B-71	B-117
4008	Lunar Sample Analysis		234		1089		B-71	B-117
4009	Returned Solar System Sample Analysis		80		1080or1086		B-71	B-117

Objective 122, Is There Extraterrestrial Life in the Solar System?

1080	Mars Surface Sample Return	1988	1700		Viking, 1090	1095 (Partial)	B-61	B-94
1081	Jupiter Atmospheric Probes	1980	205			1082	B-61	B-94
1082	Saturn Atmospheric Probes	1984	175		Venus probe	1081	B-61	B-94
1083	Titan Orbiter W/Penetrometer	1991	300		Venus probe	1092	B-61	B-94
1087	Venus Orbiter Imaging Radar W/Penetrometers	1989	225			1088	B-61	B-95
1088	Venus Lander	1985	700			1087	B-61	B-95
1090	Mars Polar Orbiter (W/Penetrometers)	1981	170			1095	B-61	B-95
1092	Titan Lander	2000	800		Viking	1083	B-61	B-95
1095	Mars Lander/Rover	1984	630		Viking	1080	B-62	B-96
1116	Crew Operated Flight To Mars		32000				B-63	B-99
4006	Synthesis of Living Matter in Labs		50				B-71	B-116
4007	Earth Fossil and Rock Analysis		61				B-71	B-117
4009	Returned Solar System Sample Analysis		80		1080		B-71	B-117

*Millions, FY 75 Dollars
( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 123, What Organic Chemistry Occurs in the Universe?

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1051	B-59	B-89
1051	5-6m Space Telescope	2000	1090		1050	1050 (Partial)	B-59	B-89
1053	Infrared Interferometer	1985 and each year	420		1103		B-59	B-89
1055	Microwave LBI	1982,1984, 1986,1988, 1990,1992	190 (180)				B-59	B-90
1072	Large Ambient IR Telescope	1982 and 1 each year until 1993	170		1103	1073 (Partial)	B-60	B-92
1073	Submillimeter Telescope	1984	160				B-60	B-92
1078	Mercury Sample Return	1999	2500		1080		B-61	B-93
1080	Mars Surface Sample Return	1988	1700		Viking		B-61	B-94
1081	Jupiter Atmospheric Probes	1980	205		Venus Probe	1082	B-61	B-94
1082	Saturn Atmospheric Probes	1984	175		Venus Probe	1081	B-61	B-94
1083	Titan Orbiter W/Penetrometer	1991	300			1092	B-61	B-94
1084	Uranus Atmospheric Probe	1984	235		1081	1093	B-61	B-94
1085	Asteroid Sample Return	1997	650		1094	1094	B-61	B-94
1086	Comet Sample Return	2000	750		1110,1111	1111	B-61	B-94
1087	Vensus Orbiter Imaging Radar W/Penetrometers	1989	225			1088	B-61	B-95
1088	Venus Lander	1985	700			1087	B-61	B-95
1089	Lunar Sample Return (Highlands)	1988	670		4008		B-61	B-95
1090	Mars Polar Orbiter (W/Penetrometers)	1986	170			1095	B-61	B-95
1091	Jupiter Orbiters Spinning/3 Axis	1985	180			1081	B-61	B-95
1092	Titan Lander	*2000*	*800*		Viking	*1083*	*B-61*	*B-95*
1093	Uranus Orbiter	1995	350			1108	B-61	B-95
1094	Asteroid Rendezvous W/Penetrometer Plus Laser	1987	260			1085	B-62	B-96
1095	Mars Lander/Rover	1984	630		Viking	1090	B-62	B-96

*Millions, FY 75 Dollars

Table B-1
Systems Listed by Objective

Objective 123, What Organic Chemistry Occurs in the Universe? (Concluded)

System		Illustrative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1096	Saturn Orbiter	1986	300			1107	B-62	B-96
1097	Neptune Orbiter	2000	450			1109	B-62	B-96
1098	Large Scale Microwave Telescope	2000	2000				B-62	B-96
1107	Jupiter-Saturn Flyby	1977	350			1096	B-62	B-98
1108	Uranus Flyby	1979	180			1093	B-63	B-98
1109	Neptune Flyby	1992	225			1097	B-63	B-98
1110	Comet Flyby/Fly-Through	1980	90			1111	B-63	B-98
1111	Comet Rendezvous	1981	210			1110	B-63	B-98
1116	Crew Operated Flight To Mars		32000				B-63	B-99
4007	Earth Fossil and Rock Analysis		60				B-71	B-117
4008	Lunar Sample Analysis		234		1089		B-71	B-117
4009	Returned Solar System Sample Analysis		80		1080 or 1085 1086 or 1087		B-71	B-117
4010	Microwave Telescope – Extraterrestrial Life		7000			1098	B-71	B-117

*Millions, FY 75 Dollars
( ) Revisit costs.

Table B-1
Systems Listed by Objective

Objective 124, Do Other Stars Have Planets?

System		Illus-trative Flight Dates	Total $*		Necessary Precursor Systems or Events	Other Comparable Data	Page Numbers for Reference	
No.	Name		R&D	OPS			$ Information	Description
1050	2.4m Space Telescope	1982,1985, 1988,1991, 1994	420 (240)			1051	B-59	B-89
1051	5-6m Space Telescope	2005	1090		1050	1050 (Partial)	B-59	B-89
1053	Infrared Interferometer	1985 and 1 each year until 1993	420		1103		B-59	B-89
1054	Large Cryogenic IR Telescope	1985 and 1 each year until 1993	200		1103		B-59	B-90
1055	Microwave LBI	1982	190 (180)				B-59	B-90

Objective 125, Can We Detect Extraterrestrial Intelligent Life?

1051	5-6m Space Telescope	2000	1090		1050		B-59	B-80
1098	Large Scale Microwave Telescope	2000	2000		4010		B-62	B-96
1113	12 Person Near Earth Orbit Space Station		7200				B-68	B-98
1115	12 Person Lunar Base		10600				B-68	B-99
4010	Microwave Telescope – Extraterrestrial Life	N.A.	7000				B-71	B-117

*Millions, FY 75 Dollars
( ) Revisit costs.

Table B-2
System Cost and Transportation Information (1000 Series)

No.	System Name	Type		Transportation System$^{(1)}$	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
		Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak$^{(2)}$ Cost/Year	Total $	
1001	Global Positioning and Communicating System – Development	✓		Shuttle/US	82	1/2	35	65	–	–	12	24/81	100	M
1002	Global Positioning and Communicating System – Operational	✓		Shuttle/US	83, 87, 88	3-1/2		100	175	25	25	50/82	300	M
1003	Expanded Coverage Comm. Navigation System – Development	✓		Shuttle/US	92	1/2		20	70	60	15	30/91	150	M
1004	Expanded Coverage Comm. Navigation System – Operational	✓		Shuttle/US	98	1-1/2				170	24	50/97	170	M
1005	Advanced Techniques Comm. Navigation System – Development	✓		Shuttle/US	99	1/2				150	22	50/98	150	L
1006	Advanced Techniques Comm. Navigation System – Operational	✓		Shuttle/US	2000	1-1/2				60	30	60/99	60	L
1007	Solar Power Technology	–	–	Ground	–	–	400	200			39	100	600	L-M
1008	Solar Power Space Test Activity		✓	Shuttle	82-85	30	200	1800	400		240	500	2400	L-M
1009	Solar Power Prototype – Development		✓	HLLV/Shuttle Manned Tug	90-95	HLLV-5 Sh-30		500	24,500	25,000	2,500	9,000	50,000	L-M
1010	Solar Power System – Operational	✓		HLLV/Shuttle Manned Tug*/US	93-98	HLLV-50 Sh-15/ year				10,000	2,500	5200	10,000	L
1011	Power Relay Technology – Development	✓		Ground	83	1	50	50			20	20	100	M
1012	Power Relay Space Testing		✓	HLLV	87-91	7		250	1,000	250	100	250	1,500	L
1013	Power Relay Prototype Development	–	✓	Tug; HLLV/Shuttle	–	–			8,000	12,000	1,350	3,000	20,000	L
1014	Hazard Waste System – Development	✓		Shuttle/Tug Electric Stage	84	2	448	1182	–	–	270	440/82	1630	L-M
1015	Hazard Waste System – Operational	✓		Shuttle/Tug Electric Stage	85-99	112	–	1186	851	2059	205	356/84	4096	L-M

*Manned Activities May Be Required to Support Experiments, Assembly, Fabrication, or Maintenance

1. US – Upper Stage
   HLLV – Heavy Lift Launch Vehicle
   OMS – Orbital Maneuvering System
2. Peak cost (FY 75 Dollars)/year in which peak cost occurs.

FF – Free Flyer
SL – Spacelab
SEP – Solar Electric Propulsion

Table B-2 (Continued)

No.	System Name	Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
		Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
1016	(Intentionally Left Blank)													
1017	(Intentionally Left Blank)													
1018	Domestic Communications System – Development	✓		Shuttle/US		1/4	20	130			19	35/83	150	M
1019	Domestic Communications System – Operational	✓		Shuttle/US	84-93	6-2/3		100	350	150	60	100/83	600	L
1020	Multi-Service Domestic Communications System – Development	✓		Shuttle/US	94	1/3			60	110	17	42/93	170	L
1021	Multi-Service Domestic Communications System – Operational	✓		Shuttle/US	94-99	6-2/3				550	83	115/93	550	L
1022	International Communications System – Development	✓		Shuttle/US	86	1/2	15	95			16	35/85	110	M
1023	International Communications System – Operational	✓		Shuttle/US	86-95	10		160	435	180	70	115/85	775	M
1024	Multi-Service International Communications System – Development	✓		Shuttle/US	96	1/2			35	100	14	45/95	135	M
1025	Multi-Service International Communications System – Operational	✓		Shuttle/US	96-99	6				385		125/95	385	M
1026	Personal Communications System – Development	–	–	Ground	–	–	15	30			7	12	45	L
1027	Personal Communications System – Operational	✓		Shuttle/US	88	1/2		5	85		15	30	90	L
1028	"Short-Term" Physical Chemical Research – Crew Operated		✓	Shuttle/ Spacelab	82-87	6	40	92	29	–	9	20/80	161	M
1029	"Long-Term" Physical Chemical Research – Crew Operated		✓	Shuttle/ Space Station	87-99	6	–		125	160	26	65/88	285	M
1030	"Short-Term" Low-g Material Science Research – Crew Operated		✓	Shuttle/ Spacelab	81-87	6	100	157	65	–	19	41/81	322	M
1031	"Long-Term" Low-g Material Science Research – Crew Operated		✓	Shuttle/ Space Station	87-99	12	–		218	367	54	130/88	585	M

*Manned Activities May Be Required to Support Experiments, Assembly, Fabrication, or Maintenance

1. US – Upper Stage
   HLLV – Heavy Lift Launch Vehicle
   OMS – Orbital Maneuvering System
2. Peak cost (FY 75 Dollars)/year in which peak cost occurs.

FF – Free Flyer
SL – Spacelab
SEP – Solar Electric Propulsion

Table B-2 (Continued)

No.	System Name	Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
		Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
1032	Commercial Processing – Crew Operated		✓	Shuttle/ Space Station	87-99	15	–	50	300	650	67	123/88	1000	M
1033	"Short-Term" Biological Materials Research – Crew Operated		✓	Shuttle/ Spacelab	81-87	.6	40	93	28	–	10	21/81	161	M
1034	"Long-Term" Biological Materials Research – Crew Operated		✓	Shuttle/ Space Station	87-99	6	–	24	93	168	27	88	285	M
1035	Preliminary Effects of Gravity on Life – Crew Operated		✓	Shuttle/ Spacelab	81-87	1-2/3	24	40	12	–	6	17/81	76	M
1036	Effects of Gravity on Life – Crew Operated		✓	Shuttle/ Space Station	87-99	3	–	11	80	68	12	31/87	159	M
1037	Human Performance in Space – Development		✓	Shuttle/ Spacelab	81-87	6	100	160	43	–	50	50	303	
1038	Human Performance in Space – Operational		✓	Shuttle/ Space Station	87-99	12-1/2	–	85	280	220	50	75/89	585	M
1039	Preliminary Disease Processes Research – Crew Operated		✓	Shuttle/ Spacelab	81-87	3-3/5	48	80	24	–	15	24/80	152	M
1040	Disease Processes Research – Crew Operated		✓	Shuttle/ Space Station	87-99	6-1/3	–	33	152	120	25	12/89	305	M
1041	Magnetic Field Change Satellite	✓		Shuttle	83, 89, 95, 01	4	–	40	40	80	8	18/82	160	M
1042	Magnetic Field Survey	✓		Shuttle	83, 89, 95, 01	4	–	45	45	85	9	15/82	175	L-M
1043	Geodetic Satellites	✓		Shuttle	83, 88	2	–	7	7	–	2	2/82	14	M
1044	Gravitational Satellites	✓		Shuttle	81, 86, 91	3	–	–	–	335	20	30/79	335	L-M
1045	Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) – Crew Operated		✓	Shuttle/ Spacelab	82,84 84(2) 85(2)	30	50	125	125	250	35	50/80	550	M
1046	Atmospheric Neutral and Charged Particle Research	✓		Shuttle	82,83,85 89,93,98	6	20	105 (25)	(25)	(65)	25	–	125 (115)	M
1047	Electrodynamic Explorer	✓		DELTA or Shuttle/Tug	79	1	50	–	–	–	15	23/79	50	H

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2. Peak cost (FY 75 dollars)/year in which peak cost occurs

Table B-2 (Continued)

No.	System Name	Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
		Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
1048 *	Wide Field X-Ray and Gamma Ray	√		Shuttle	84, 89	1 1	5	75	(25)		20	30/82	80 (25)	L
1049	1m UV Telescope		√	Shuttle SLP	84, 87, 90	4	35	50	15	–	14	30/81	100	M
1050 *	2.4m Space Telescope (LST)	√		Shuttle OMS	83, 84, 87 90	5	250 –	170 (60)	– (60)	– (120)	40	80/81	420 (240)	H
1051	5-6m Space Telescope	√		Advanced Shuttle	2000	1	–			1090	110	250/98	1090	L-M
1052	Small Submillimeter Receiver	√		Shuttle SL or FF	82	10	10	5	5		2	5/81	20	L
1053	Infrared Interferometer		√	Shuttle SLP	85 & each year	8		200	100	120	20	100/84	420	L-M
1054	Large Cryogenic IR Telescope		√	Shuttle SL	84 & each year	8	25	150	10	15	20	60/80	200	M
1055 *	Microwave LBI	√		Shuttle SL or FF	83,84,86 88,90,92	1 5	120	70 (35)	– (110)	– (35)	20	60/80	190 (180)	M
1056 *	High Energy Astrophysics Spacelab Cluster	√		Shuttle	82, 84, 86, 88, 90	1 4	310	– (100)	– (100)	– (25)	27	100/79	310 (225)	M
1057 *	Large Area Gamma-Ray Detector	√		Shuttle	86, 90	1 1	– –	120 –	30 (40)	– –	15	45/85	150 (40)	L-M
1058	Low Energy Gamma Explorers	√		Shuttle/US	84, 85	2	14	56	10	–	10	20/82	80	M
1059 *	Large X-Ray Telescope	√		Shuttle	90, 95	1 1	– –	15 –	355 –	– (65)	37	105/89	370 (65)	M
1060 *	1.2 Meter X-Ray Telescope	√		Shuttle	82, 85	1 1	120	90 (45)			30	60/80	210 (45)	H
1061 *	Heavy Cosmic Ray Detector	√		Shuttle	84, 87, 89	1 2	10 –	100 –	80 (35)	– (35)	15	40/84	190 (70)	M
1062	Relativity Experiments in Earth Orbit with Freely Spinning Gyroscope	√		Shuttle	83	1	25	75	–	–	10	12/81	100	L

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Table B-2 (Continued)

No.	System Name	Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
		Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
1063	Gravity Wave Detector	✓		Shuttle	86	1	–	50	45	–	10	20/84	95	L
1064	EOTVOS Effect Experiment		✓	Shuttle/SL	83	1	25	50	–	–	15	25/81	75	L
1065	Stable Clock/Gyro in Solar Orbit	✓		Shuttle/Tug	92	1	–	–	185	115	20	70/90	300	M
1066	Mercury Orbiter (W/Penetrometers)	✓		Shuttle/Tug SEP	85	1	–	190	75	–	55	70/84	265	M
1067	Interplanetary Near-Sun Probe	✓		Shuttle/Tug SEP	84	1	–	135	–	–	15	50/84	135	L
1068	700 Kilogram X-Ray Monitor	✓		Shuttle	81	1	25	40	–	–	12	16/80	65	M
1069	Solar System Escape Spacecraft	✓		T III/Centaur	80	1	175	50			20	50/79	225	H
1070 *	10,000 Kg Solar Observatories	✓		Shuttle	85, 87, 89, 91, 93	1 4	20	480	– (130)	– (130)	65	140/84	500 (260)	L-M
1071	Observatory in Solar Polar Orbit	✓		T III Centaur	83	1		170	30	–	40	55/82, 83	200	M
1072	Large Ambient IR Telescope		✓	Shuttle/SL	82 & each yr	8	20	100	30	20	14	50/82	170	M-H
1073	Submillimeter Telescope	✓		Shuttle/FF	84	1	10	110	40	–	20	35/83	160	M
1074	Low Frequencies LBI	✓		Shuttle/Tug	87	3	–	80	230	–	40	75/86	310	L-M
1075	Spacelab Solar Telescope Cluster		✓	Shuttle/SL	81	1-2 per yr - 10 yrs	45	170	105	–	25	50/83	320	L-M
1076	Solar Monitor	–	✓	Shuttle/SL	81	1 per yr	–	5	5	10	1	1	20	M
1077 *	1600 Kg Solar Observatory	✓		DELTA or Shuttle	79, 81, 83, 85, 87, 89, 91	1 6	60	10 (45)	– (45)	– (25)	10	30/78	70 (115)	M-H

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Table B-2 (Continued)

No.	System Name	Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
		Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
1078	Mercury Sample Return	✓		Shuttle/Tug SEP	99	1	–			2000	500	330/98	2500	L-M
1079	Venus Surface Sample Return	✓		Shuttle/Tug	94	1	–	–	–	2300	85	185/93	2300	M
1080	Mars Surface Sample Return	✓		Shuttle/Tug	88	1	–	100	1540	60	90	450/87	1700	M
1081	Jupiter Atmospheric Probes	✓		T III E/ Centaur	80	1	100	55	50	–	19	50/79	205	H
1082	Saturn Atmospheric Probes	✓		Shuttle/IUS	84	1	–	150	20	5	16	45/82	175	M
1083	Titan Orbiter W/Penetrometer	✓		Shuttle/Tug	91	1	–	–	200	100	20	79/90	300	L-M
1084	Uranus Atmospheric Probe	✓		Shuttle/Tug	84	1	–	200	35	–	15	47/82	235	L-M
1085	Asteroid Sample Return	✓		Shuttle/Tug	97	1	–	–	–	650	50	150/95, 96	650	L-M
1086	Comet Sample Return	✓		Shuttle/Tug SEP	2000	1	–	–	–	700	50	178/98, 99	750	L
1087	Venus Orbiter Imaging Radar W/Penetrometers	✓		Shuttle/Tug	89	1	–	10	205	10	25	65/88	225	M
1088	Venus Lander	✓		Shuttle/US	85	1	–	450	250	–	50	120/84	700	M
1089	Lunar Sample Return (Highlands)	✓		Shuttle/US	88	1	–	90	580	–	100	180/88	670	H
1090	Mars Polar Orbiter (W/Penetrometers)	✓		Atlas Centaur	81	1	100	70	–	–	20	45/80	170	M-H
1091	Jupiter Orbiters Spinning/3 Axis	✓		Shuttle/US or T III/Centaur	85	1		135	45	–	35	98/80	180	M
1092	Titan Lander	✓		Shuttle/Tug	2000	1	–	–	–	700	63	200/99	800	L-M
1093	Uranus Orbiter	✓		Shuttle/Tug	95	1	–	–	–	350	30	79/94	350	L-M

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2. Peak cost (FY 75 dollars)/ year in which peak cost occurs

Table B-2 (Continued)

No.	System Name	Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
		Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
1094	Asteroid Rendezvous W/Penetrometer Plus Laser	√		Shuttle/Tug	87	1	–	60	160	40	30	67/85	260	M-H
1095	Mars Lander/Rover	√		Shuttle/US or T III E/ Centaur	85	1	95	500	35	–	65	140/82	630	M-H
1096	Saturn Orbiter	√		Shuttle/Tug	86	1	–	200	100	–	25	105/85	300	M
1097	Neptune Orbiter	√		Shuttle/Tug/ SEP	2000	1	–	–	–	450	25	80/99	450	L-M
1098	Large Scale Microwave Telescope	√		Shuttle	2000	1	–			2000	200	–	2000	L
1099	200-1000 A UV Telescope	√		Shuttle	84	1	20	150	–	–	20	50/83, 84	170	M
1100 *	400 Kg UV Telescope Free Flyer	√		Shuttle	81, 86, 91, 96, 2001	1 4	75 –	30 (10)	– (20)	– (35)	8	25/79	105 (65)	M
1101	Wide Field UV Survey	√		Shuttle/SL	81 & every 3/4 yr.	30	25	25	25	50	10	10/79	125	M
1102	Very Wide Field Optical Telescope	√		Shuttle/SL	82 & every yr.	4	2	2				–	4	M
1103 *	Cryogenic IR Survey Satellite	√		DELTA or Shuttle	81, 84, 89	1 2	–	26 (20)	19 (20)	– –	9	15/81	45 (40)	H
1104	Lunar Polar Orbiter	√		Atlas/ Centaur	80	1	85	15	–	–	25	25/79	100	H
1105	Lunar Orbiter W/Penetrometers	√		Shuttle/US	83	1		180			25	48/81	180	M
1106	Lunar Rover Unmanned	√		Shuttle/US	88	1		250	300	–	75	100/87	550	M
1107	Jupiter-Saturn Flyby	√		T III E/ Centaur	77	2	350	–	–	–	70	85/76	350	H

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3. Does not include costs for experiments or experiment modules.
4. Costing assumes modular space station 1113, (has not been developed).

Table B-2 (Continued)

No.	System Name	Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
		Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
1108	Uranus Flyby	√		T III E/ Centaur	79	1	165	15	–	–	20	96/78	180	M-H
1109	Neptune Flyby	√		T III E/ Centaur	92	1	–	–	50	175	20	50/91, 92	225	M
1110	Comet Flyby/Fly-Through	√		T III E/ Centaur	80	1	90	–	–	–	20	47/80	90	H
1111	Comet Rendezvous	√		T III Centaur or Shuttle	81	1	150	60	–	–	25	71/79	210	M
1112	4 Person Near Earth Orbit Space Station [3]		√	Shuttle	85–89 86	4/yr.	–	1000 160	250 390	500 300	88 49	270/84 175/86	1750 850 2600	M M
1113	12 Person Near Earth Orbit Space Station [3]		√	Shuttle	87	4/yr.	–	1400	2230	2300	300	1000/86	5930	L
1114	12 Person Geosynch Space Station [3, 4]		√	Shuttle/Tug	89	4/yr.	–	500	4900	6,300	685	1700/88	11,700	L-M
1115	12 Person Lunar Base		√	Shuttle/Tug	95	?	–	–	220	10,700	990	2320/95	11,910	L-M
1116	Crew Operated Flight To Mars		√	Shuttle/Tug	2000	?	–	–	–	27,000	2600	9000/2000	31,000	L-M
1117	Industrial Space Facility[4]		√	HLLV	95	?	–	–	100	24,000	2400	5700/95	24,100	L

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Table B-2 (Continued)

No.	System		Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
	Name	Used With System(s)	Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
2001	High Resolution Visible – IR System – Development	3001,3021, 3007,3038, 3013,3069, 3025,3071	√		Shuttle/ US	81	1/2	92	63	–	–	26	45/81	155	H
2002	High Resolution Visible – IR System – Operational	3002,3022, 3026,3031, 3008,3070, 3014,3072	√		Shuttle/ US	82-86	5-1/2	–	325	240	–	83	150/82	565	M
2003	Very High Resolution Visible – IR System – Development	3015,3003, 3027,3023, 3069,3071, 3040	√		Shuttle/ US	87	1/2	–	86	119	–	25	45/85	205	M
2004	Very High Resolution Visible – IR System – Operational	3024,3016 3039,3004, 3040,3028, 3070,3072	√		Shuttle/ US	88-94	5-1/2	–	–	200	465	67	105/89	665	M
2005	All Weather Survey System – Development	3005,3040, 3017,3069, 3029,3071	√		Shuttle/ US	97	1/2	–	–	10	255	27	40/87	265	M
2006	All Weather Survey System – Operational	3006,3024, 3018,3041, 3030,3070, 3072	√		Shuttle/ US	98	1/2	–	–	–	110	55	70/99	110	L
2007	Long Wavelength Microwave System – Development	3003, 3019, 3007	√	√	Shuttle/ US	86	1/2	–	110	140	–	42	60/85	250	L-M
2008	Long Wavelength Microwave System – Operational	3004, 3010, 3019, 3008	√		Shuttle/ US	87-90	2-1/2	–	21	194	–	21	21	215	L-M
2009	High Resolution Long Wavelength Microwave System – Development	3005, 3011, 3019	√	√	Shuttle/ US	92	1/2	–	–	7	293	30	62/92	300	L-M
2010	High Resolution Long Wavelength Microwave System – Operational	3006, 3012, 3020	√	–	Shuttle/ US	93-98	2-1/2	–	–	–	260	52	53/96	260	L-M

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Table B-2
System Cost and Transportation Information (2000 Series)

No.	System		Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
	Name	Used With System(s)	Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
2011	Weather Survey System I – Development	3038,3054, 3069,3009, 3031, 3019	√		Shuttle/ US	84	1/4	20	50	–	–	10	20/83	70	H
2012	Weather Survey System I – Operational	3039,3055, 3069,3032, 3019,3037	√		Shuttle/ US	85–88	3/4		30	70	–	14	25/87	100	H
2013	Passive-Active Sensors, Large Scale Weather Survey System – Development	3040,3056, 3069,3033	√		Shuttle/ US	90	1/2		20	80		14	25/89	100	M
2014	Passive-Active Sensors, Large Scale Weather Survey System – Operational	3039,3057, 3040,3034, 3070,3037, 3019	√		Shuttle/ US	91–96	3-1/2			15	235	25	50/95	250	M
2015	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development	3040,3058, 3069,3035, 3019	√		Shuttle/ US	2000	1/2			10	90	10	25/99	100	L
2016	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational	3020,3059, 3041,3036, 3037	√		Shuttle/ US	2001	1/2				50	50	50/2000	50	L
2017	Earth Energy Budget Monitoring System – Development	3038	√		Shuttle/ US	81	1/2	25	15	–	–	8	15/80	40	M
2018	Earth Energy Budget Measuring System – Operational	3039	√		Shuttle/ US	82-86	1-1/2	–	90	60	–	25	40/–	150	M
2019	Advanced Earth Energy Budget Monitoring System – Development	3040	√		Shuttle/ US	87	1/2	–	35	45	–	15	30/86	80	M
2020	Advanced Earth Energy Budget Monitoring System – Operational	3041	√		Shuttle/ US	87-98	3-1/2	–	–	110	310	30	45/–	420	L
2021	Air Pollution Technology Satellite – Development	3060, 3042	√		Shuttle/ US	83	1/2	25	35	–	–	10	20/82	60	H

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Table B-2 (Continued)

No.	System		Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
	Name	Used With System(s)	Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
2022	Stratospheric Monitoring System – Development	3043, 3038	√		Shuttle/ US	85	1/2	–	60	–	–	9	9	60	M
2023	Stratospheric Monitoring System – Operational	3044, 3039	√		Shuttle/ US	86, 88, 89	1-1/2	–	20	80	–	12	20/86	100	M
2024	Stratospheric Constituents Monitoring System – Development	3045, 3040	√	√	Shuttle/ US	91	1/2	–	–	65	10	15	15	75	L
2025	Stratospheric Constituents Monitoring System – Operational	3046, 3041	√		Shuttle/ US	91, 96, 97	2-1/2	–	–	–	230	36	36	230	L
2026	Sea Survey Technology Satellite	3049	√		Shuttle/ US	82	1/2	30	40			17	30/81	70	H
2027	Sea Survey System – Development	3038, 3050	√	√	Shuttle/ US	85	1/2	–	70	–	–	17	30/84	70	H
2028	Sea Survey System – Operational	3051, 3039	√		Shuttle/ US	86-89	3-1/2	–	30	140	40	30	40/86	210	M
2029	High Resolution Sea Survey System – Development	3052, 3040	√	√	Shuttle/ US	91	1	–	–	90	20	28	40/90	110	L
2030	High Resolution Sea Survey System – Operational	3053, 3041	√		Shuttle/ US	92-97	3-1/2	–	–	–	250	31	50/92	250	L
2031	VISSR Atmospheric Sounder System – Development	3054, 3031,	√	√	Shuttle/ US	83	1/2	14	76	–	–	15	30/82	90	M-H
2032	VISSR Atmospheric Sounder System – Operational	3055, 3032	√		Shuttle/ US	84, 86, 87	1-1/2	–	30	150	–	30	52/89	180	M-H
2033	Storm Satellite Survey System – Development	3056, 3033,	√	√	Shuttle/ US	89	1/2	–	26	174	–	29	48/87	200	M

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Table B-2 (Continued)

No.	System		Type		Transportation System(1)	Illustrative Flight Date(s)	No. of Equivalent Flight(s)	Cost Estimate							Cost Confidence Level
	Name	Used With System(s)	Free Flyer	Manned*				76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
2034	Storm Satellite Survey System – Operational	3034, 3057	√		Shuttle/ US	90, 94 95	2-1/2	–	–	–	290	41	82/96	290	M
2035	Synchronous Earth Observatory Survey System – Development	3058, 3035	√		Shuttle & US	88	1/2		55	55		17	35/87	110	M
2036	Synchronous Earth Observatory Survey System – Operational	3059, 3036	√		Shuttle & US	88-92	2-1/2		50	100	130	13	30/88	280	M
2037	Global Tropospheric Monitoring System – Development	3061	√	–	Shuttle & US	88	1/2	–	20	110	–	19	40/95	130	M
2038	Global Tropospheric Monitoring System – Operational	3062	√	–	Shuttle & US	89-95	1	–	–	70	70	28	60/88	140	M
2039	Regional Tropospheric Monitoring System – Development	3063	√	–	Shuttle & US	96	1/2		–	–	225	45	70/95	225	L
2040	Regional Tropospheric Monitoring System – Operational	3064	√	–	Shuttle/ US	97	1				300	30	48/80	300	L
2041	Earthquake Prediction System – Development	4001	√	–	Shuttle	91-92	1	2	8	50	150	8	60/91	210	L
2042	Earthquake Prediction System – Operational	4002	√	–	Shuttle	95-99	1				150	15	25/94	150	L

1. US – Upper Stage
   HLLV – Heavy Lift Launch Vehicle
   OMS – Orbital Maneuvering System
   FF – Free Flyer
   SL – Spacelab
   SEP – Solar Electric Propulsion
2. Peak cost (FY 75 dollars)/year in which peak cost occurs
3. Does not include the cost associated with space station experiment module

Table B-2
System Cost and Transportation Information (3000 Series)

No.	System		Cost Estimate							Cost Confidence Level
	Name	Used With System(s)	76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
3001	Global Wheat Prediction System – Development	2001	24	18	–	–	6	9	42	H
3002	Global Wheat Prediction System – Operational	2002		10	30	30	10	10	70	M
3003	Global All Crop Prediction System – Development	2003,2007	–	18	36	–	6	11	54	M
3004	Global All Crop Prediction System – Operational	2004,2008			30	95	10	10	125	M
3005	All Weather Global All Crop Prediction System – Development	2005,2009	–	–	4	85	10	12	89	M
3006	All Weather Global All Crop Prediction System – Operational	2006,2010				15	15	15/99	15	L
3007	Water Resource System I – Development	2001	20	10	–	–	6	6	30	H
3008	Water Resource System I – Operational	2002	–	9	12	–	3	3	21	M
3009	Watershed Runoff Forecast System – Development	2007	–	18	24	–	6	6	42	M
3010	Watershed Runoff Forecast System – Operational	2008	–	12	24	–	12	12	36	M
3011	Regional Water Balance Forecast System – Development	2009	–	–	3	30	3	3	33	M
3012	Regional Water Balance Forecast System – Operational	2010	–	–	–	52	5	5	52	M
3013	Surface Cover Change Detection System – Development	2001	20	10	–	–	5	5	30	H
3014	Surface Cover Change Detection System – Operational	2002	–	120	60	–	26	30/82	180	M
3015	Critical Environmental Area Monitoring System – Development	2003	–	16	24	–	6	6/85	40	M
3016	Critical Environmental Area Monitoring System – Operational	2004	–	–	80	180	24	50/90	260	M
3017	Land Capability System – Development	2005	–	–	5	50	5	5	55	L
3018	Land Capability System – Operational	2006	–	–	–	40	20	20/98	40	L
3019	Living Marine Resources System – Development	2007,2008 2009	3	20	25	62	6	8	110	M
3020	Living Marine Resources System – Operational	2010			–	15*	15*	15	15	L
3021	Broad Area Timber Inventory System – Development	2001	11	4	–	–	2	3/79	15	H
3022	Broad Area Timber Inventory System – Operational	2002	11	4	–	–	2	3/79	15	M
3023	Specific Area Timber Inventory System – Development	2003	–	6	9	–	2	3/87	15	M
3024	Specific Area Timber Inventory System – Operational	2004,2006	–	6	29	–	2	3/87	35	L
3025	Range Forage Status System – Development	2001	7	3	–	–	1	3/80	10	M
3026	Range Forage Status System – Operational	2002	4	6		–	2	2	10	M

*One year of operation only.

2. Peak cost (FY 75 dollars)/year in which peak cost occurs

Table B-2 (Continued)

No.	System		Cost Estimate							Cost Confidence Level
	Name	Used With System(s)	76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
3027	Range Forage Prediction System – Development	2003	–	6	9	–	2	3/87	15	M
3028	Range Forage Prediction System – Operational	2004	–	–	12	8	3	3	20	M
3029	All Weather Range Forage System – Development	2005	–	–	2	28	3	3/95	30	L
3030	All Weather Range Forage System – Operational	2006	–	–	–	3	3	3/99	3	L
3031	Global Atmospheric Research Program System – Development	2011,2031	9	11			3	3	20	H
3032	Global Atmospheric Research Program System – Operational	2012,2032	–	17	13		4	5/86	30	H
3033	Post-GARP System – Development	2013,2033		7	17		3	3	24	H
3034	Post-GARP System – Operational	2014,2034			7	59	6	7/90	66	H
3035	Advanced Techniques Weather System – Development	2015,2035			2	18	2	2	20	M
3036	Advanced Techniques Weather System – Operational	2016,2036				10	3	10/99	10	M
3037	Weather Modification Experiments Monitoring System	2011,2016 2031,2036		15	15	30	3	3	60	M
3038	Climate Parametric Systems Study – Development	2017*	40	25	–	–	10	19/80	65	M
3039	Climate Parametric System Study – Operational	2018*	–	175	100	–	40	60/85	275	M
3040	Climate Forecasting System – Development	2019*	–	70	70	–	20	50/86	140	L
3041	Climate Forecasting System – Operational	2020*	–	–	120	355	30	70/91	475	L
3042	Stratospheric Parameter Experimental System – Development	2021	4	6	–	–	2	2	10	M
3043	Preliminary Stratospheric Prediction System – Development	2022	–	10	–	–	2	2	10	L
3044	Preliminary Stratospheric Prediction System – Operational	2023	–	5	20	–	3	3	25	M
3045	"3 Dimensional" Stratospheric Prediction System – Development	2024	–	–	12	8	4	4	20	L
3046	"3 Dimensional" Stratospheric Prediction System – Operational	2025	–	–	–	60	6	6	60	L

2. Peak Cost (FY 75 dollars)/year in which peak cost occurs

*Also 2001-2004, 2007-2010, 2011-2016, 2020, 2025, 2026-2030, and 1076.

Table B-2 (Continued)

No.	System		Cost Estimate							Cost Confidence Level
	Name	Used With System(s)	76-80	81-85	86-90	91-2000	Average Cost	Peak$^{(2)}$ Cost/Year	Total $	
3047	Water Quality Monitoring System – Development	–		3	5	12	1		20	M
3048	Water Quality Monitoring System – Operational	–		3	12	25	2		40	M
3049	Marine Parameter Experimental System – Development	2026	3	10	2	–	4	5/81	15	H
3050	Marine Forecasting System – Development	2027	–	15	–	–	4	5/85	15	H
3051	Marine Forecasting System – Operational	2028	–	4	24	12	6	6	40	M
3052	Extended Parameter Marine Forecasting System – Development	2029	–	–	16	6	5	6/93	22	M
3053	Extended Parameter Marine Forecasting System – Operational	2030	–	–	–	50	6	6	50	L
3054	Cyclonic Scale Severe Weather Predictions System – Development	2031,2011	6	16	–	–	3	3	22	M
3055	Cyclonic Scale Severe Weather Predictions System – Operational	2032,2012	–	10	30	–	5	5	40	M
3056	Thunderstorm Scale Severe Weather Prediction System – Development	2033,2013	–	12	29	–	7	7	41	M
3057	Thunderstorm Scale Severe Weather Prediction System – *Operational*	2034,2014	–	–	6	54	6	6	60	M
3058	Day-Night Severe Storm Prediction – Development	2035,2015				24	6	6	24	L
3059	Day-Night Severe Storm Prediction – Operational	2036,2016	–	–	–	15	15	15	15	L
3060	Tropospheric Parameter Experimental System	2021	10	20			3	3	30	H
3061	Global Air Pollution Analysis System – Development	2037			20		4	4	20	M
3062	Global Air Pollution Analysis System – Operational	2038			10	60	10	10	70	M
3063	Regional Air Pollution Prediction System – Development	2039				28	3	3	28	L
3064	Regional Air Pollution Prediction System – Operational	2040				135	27	27	135	L
3065	Hazard Warning System – Development	–		5	5	10	2	2	20	M
3066	Hazard Warning System – Operational	–		10	10	20	4	4	40	M
3067	Extended Hazard Warning System – Development	–	–	5	5	10	2	2	20	M
3068	Extended Hazard Warning System – Operational	–	–	10	10	20	4	4	40	M
3069	Disease Vectors System – Development	2001 2003,2005	6	10	12	22	2	3/89	50	M
3070	Disease Vectors System – Operational	2002,2004, 2006		20	25	48	5	5	93	L
3071	Geological Mapping System – Development	2001,2003, 2005	4	5	5	9	1	1	23	M
3072	Geological Mapping System – Operational	2002,2004 2006	12	15	15	27	3	3	69	M

2. Peak cost (FY 75 dollars)/year in which peak cost occurs

Table B-2
System Cost and Transportation Information (4000 Series)

No.	System Name	Cost Estimate							Cost Confidence Level
		76-80	81-85	86-90	91-2000	Average Cost	Peak(2) Cost/Year	Total $	
4001	Earthquake Parameters – Development	70	80			10	50/81	150	L
4002	Very Long Baseline Interferometry		10	10	20	2	–	40	M
4003	Oceanographic Research	–	9	6	15	1.5	–	30	M
4004	Low Atmospheric Research	–	10	10	20	2	–	40	H
4005	Strato/Mesosphere Research	–	15	15	30	3	–	60	M
4006	Synthesis of Living Matter in Labs	10	10	10	20	2	2	50	M
4007	Earth Fossil and Rock Analysis	12	12	12	25	2.5	2.5	61	L
4008	Lunar Sample Analysis	40	30	64	100	9	20/89	234	L
4009	Returned Solar System Sample Analysis	–	–	–	80	8	12/93	80	L
4010	Microwave Telescope – Extraterrestrial Life	75	1400	1845	3690	280	369	7010	L
4011	Ionosphere-Magnetosphere Coupling Analysis	–	15	15	30	3	3	60	M

2. Peak cost (FY 75 dollars)/year in which peak cost occurs

Table B-3
System/Objective Matrix: 1000 Series

System		Theme 3						Theme 4				Theme 5			Theme 6						
No.	Name	031	032	033	034	035	036	041	042	043	044	051	052	053	061	062	063	064	065	066	067
1001	Global Positioning and Communicating System – Development				X																
1002	Global Positioning and Communicating System – Operational				X																
1003	Expanded Coverage Comm. Navigation System – Development				X																
1004	Expanded Coverage Comm. Navigation System – Operational				X																
1005	Advanced Techniques Comm. Navigation System – Development				X																
1006	Advanced Techniques Comm. Navigation System – Operational				X																
1007	Solar Power Technology							X	X												
1008	Solar Power Space Test Activity							X													
1009	Solar Power Prototype – Development							X													
1010	Solar Power System – Operational							X													
1011	Power Relay Technology – Development								X												
1012	Power Relay Space Testing								X												
1013	Power Relay Prototype Development								X												
1014	Hazard Waste System – Development									X											
1015	Hazard Waste System – Operational									X											
1016	(Intentionally Left Blank)																				
1017	(Intentionally Left Blank)																				
1018	Domestic Communications System – Development											X									
1019	Domestic Communications System – Operational											X									
1020	Multi-Service Domestic Communications System – Development											X									
1021	Multi-Service Domestic Communications System – Operational											X									
1022	International Communications System – Development												X								
1023	International Communications System – Operational												X								
1024	Multi-Service International Communications System – Development												X								

Table B-3
System/Objective Matrix; 1000 Series

System		Theme 3						Theme 4				Theme 5			Theme 6						
No.	Name	031	032	033	034	035	036	041	042	043	044	051	052	053	061	062	063	064	065	066	067
1025	Multi-Service International Communications System – Operational												X								
1026	Personal Communications System – Development													X							
1027	Personal Communications System – Operational													X							
1028	"Short Term" Physical Chemical Research – Crew Operated														X						
1029	"Long-Term" Physical Chemical Research – Crew Operated														X						
1030	"Short-Term" Low-g Material Science Research – Crew Operated															X					
1031	"Long-Term" Low-g Material Science Research – Crew Operated															X					
1032	Commercial Processing – Crew Operated																X				
1033	"Short-Term" Biological Materials Research – Crew Operated																	X			
1034	"Long-Term" Biological Materials Research – Crew Operated																	X			
1035	Preliminary Effects of Gravity on Life – Crew Operated																		X		
1036	Effects of Gravity on Life – Crew Operated																		X		
1037	Human Performance in Space – Development																			X	
1038	Human Performance in Space – Operational																			X	
1039	Preliminary Disease Processes Research – Crew Operated																				X
1040	Disease Processes Research – Crew Operated																				X

Table B-3 (Continued)
System/Objective Matrix: 1000 Series

System		Theme 7						Theme 8					Theme 9				Theme 10					Theme 11				Theme 12				
No.	Name	071	072	073	074	075	076	081	082	083	084	085	091	092	093	094	101	102	103	104	105	111	112	113	114	121	122	123	124	125
1041	Magnetic Field Change Satellite	X					X																		X					
1042	Magnetic Field Survey	X					X																		X					
1043	Geodetic Satellites		X	X																										
1044	Gravitational Satellites		X	X																										
1045	Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) Crew Operated	X				X	X													X			X	X	X					
1046	Atmospheric Neutral and Charged Particle Research					X	X																X	X		Plus Obj. 024				
1047	Electrodynamic Explorer						X													X	X		X		X					
1048	Wide Field X-Ray and Gamma Ray							X			X		X			X	X													
1049	1m UV Telescope							X			X			X	X	X	X		X	X	X		X	X						
1050	2.4m Space Telescope							X	X	X	X	X	X	X	X	X	X		X	X	X		X	X				X	X	
1051	5-6m Space Telescope							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
1052	Small Submillimeter Receiver							X	X																					
1053	Infrared Interferometer								X	X				X			X	X										X	X	
1054	Large Cryogenic IR Telescope								X	X	X			X			X	X			X	X	X						X	
1055	Microwave LBI								X	X			X	X			X	X										X	X	
1056	High Energy Astrophysics Spacelab Cluster							X		X	X		X	X	X	X														
1057	Large Area Gamma-Ray Detector							X		X	X		X	X	X	X	X													
1058	Low Energy Gamma Explorers							X		X			X	X		X	X													
1059	Large X-Ray Telescope							X	X	X	X		X	X	X	X	X		X		X									
1060	1.2 Meter X-Ray Telescope							X	X	X	X		X	X			X				X									
1061	Heavy Cosmic Ray Detector							X		X	X		X	X	X	X	X				X									
1062	Relativity Experiments in Earth Orbit with Freely Spinning Gyroscope											X																		
1063	Gravity Wave Detector									X		X	X	X																
1064	EOTVOS Effect Experiment											X																		
1065	Stable Clock/Gyro in Solar Orbit											X																		
1066	Mercury Orbiter (W/Penetrometers)											X								X		X	X		X					
1067	Interplanetary Near-Sun Probe						X					X				X			X	X			X		X					
1068	700 Kilogram X-Ray Monitor							X		X			X	X			X													
1069	Solar System Escape Spacecraft												X		X	X	X			X										

Table B-3 (Continued)
System/Objective Matrix: 1000 Series

System		Theme 7						Theme 8					Theme 9				Theme 10					Theme 11				Theme 12				
No.	Name	071	072	073	074	075	076	081	082	083	084	085	091	092	093	094	101	102	103	104	105	111	112	113	114	121	122	123	124	125
1070	10,000 Kg Solar Observatories			X		X	X								X	X			X	X	X			X	X					
1071	Observatory in Solar Polar Orbit															X			X	X	X				X					
1072	Large Ambient IR Telescope								X	X	X				X		X	X			X	X	X	X				X		
1073	Submillimeter Telescope							X	X	X							X	X	X									X		
1074	Low Frequencies LBI												X	X			X			X					X					
1075	Spacelab Solar Telescope Cluster	X				X	X								X	X			X	X					X					
1076	Solar Monitor			X		X	X												X	X	X			X		Plus Obj. 023				
1077	1600 Kg Solar Observatory					X	X								X	X			X	X	X			X						
1078	Mercury Sample Return																	X	X			X	X		X			X		
1079	Venus Surface Sample Return																					X	X		X					
1080	Mars Surface Sample Return																					X	X		X	X	X	X		
1081	Jupiter Atmospheric Probes																					X	X	X	X		X	X		
1082	Saturn Atmospheric Probes																					X	X	X	X		X	X		
1083	Titan Orbiter W/Penetrometer																					X	X	X	X		X	X		
1084	Uranus Atmospheric Probe																					X	X	X				X		
1085	Asteroid Sample Return														X	X						X	X					X		
1086	Comet Sample Return														X		X					X	X			X		X		
1087	Venus Orbiter Imaging Radar W/Penetrometers																					X	X	X	X		X	X		
1088	Venus Lander																					X	X	X			X	X		
1089	Lunar Sample Return (Highlands)															X			X			X	X		X			X		
1090	Mars Polar Orbiter (W/Penetrometers)																					X	X	X	X		X	X		
1091	Jupiter Orbiters Spinning/3 Axis																					X	X	X	X			X		
1092	Titan Lander																					X	X	X	X	X	X	X		
1093	Uranus Orbiter																					X	X	X	X			X		
1094	Asteroid Rendezvous W/Penetrometer Plus Laser																					X	X		X			X		
1095	Mars Lander/Rover																					X	X	X	X	X	X	X		
1096	Saturn Orbiter																					X	X	X	X			X		
1097	Neptune Orbiter																					X	X	X	X			X		
1098	Large Scale Microwave Telescope								X	X			X				X	X										X		X
1099	200-1000 A UV Telescope													X	X		X			X	X									
1100	400 Kg UV Telescope Free Flyer							X			X			X	X		X		X	X	X		X	X						

Table B-3 (Continued)
System/Objective Matrix: 1000 Series

System		Theme 7						Theme 8					Theme 9				Theme 10					Theme 11				Theme 12				
No.	Name	071	072	073	074	075	076	081	082	083	084	085	091	092	093	094	101	102	103	104	105	111	112	113	114	121	122	123	124	125
1101	Wide Field UV Survey								X								X													
1102	Very Wide Field Optical Telescope							X	X	X	X						X													
1103	Cryogenic IR Survey Satellite								X	X							X	X			X	X	X							
1104	Lunar Polar Orbiter																					X	X		X					
1105	Lunar Orbiter W/Penetrometers																					X	X							
1106	Lunar Rover Unmanned																					X	X		X					
1107	Jupiter-Saturn Flyby																					X	X	X	X			X		
1108	Uranus Flyby																					X	X	X	X			X		
1109	Neptune Flyby																					X	X	X	X			X		
1110	Comet Flyby/Fly-Through																					X						X		
1111	Comet Rendezvous																X					X	X					X		
1112	4 Person Near Earth Orbit Space Station*																													
1113	12 Person Near Earth Orbit Space Station*																													X
1114	12 Person Geosynch Space Station*																													
1115	12 Person Lunar Base*																					X	X		X	X				X
1116	Crew Operated Flight To Mars*																					X	X	X	X	X	X	X		
1117	Industrial Space Facility*																													

*Elements of many themes as discussed in Chapters 5, 6, and 9.

Table B-3 (Continued)
System/Objective Matrix: 2000 Series

System		Theme 1						Theme 2						Theme 3						Theme 4	Theme 7						Theme 11			
No.	Name	011	012	013	014	015	016	021	022	023	024	025	026	031	032	033	034	035	036	044	071	072	073	074	075	076	111	112	113	114
2001	High Resolution Visible – IR System – Development	X	X	X		X	X			X									X	X										
2002	High Resolution Visible – IR System – Operational	X	X	X		X	X			X									X	X										
2003	Very High Resolution Visible – IR System – Development	X		X		X	X			X									X	X										
2004	Very High Resolution Visible – IR System – Operational	X		X		X	X			X									X	X										
2005	All Weather Survey System – Development	X		X		X	X			X									X	X										
2006	All Weather Survey System – Operational	X		X		X	X			X									X	X										
2007	Long Wavelength Microwave System – Development	X	X		X					X									X											
2008	Long Wavelength Microwave System – Operational	X	X		X					X									X											
2009	High Resolution Long Wavelength Microwave System – Development	X	X		X					X									X											
2010	High Resolution Long Wavelength Microwave System – Operational	X	X		X					X									X											
2011	Weather Survey System I – Development							X	X	X				X					X					X						
2012	Weather Survey System I – Operational							X	X	X				X					X					X						
2013	Passive-Active Sensors, Large Scale Weather Survey System – Development							X	X	X				X					X					X						
2014	Passive-Active Sensors, Large Scale Weather Survey System – Operational							X	X	X				X					X					X						
2015	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development							X	X	X				X					X					X						
2016	Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational							X	X	X				X					X					X						
2017	Earth Energy Budget Monitoring System – Development									X																				
2018	Earth Energy Budget Measuring System – Operational									X																				
2019	Advanced Earth Energy Budget Monitoring System – Development									X																			X	
2020	Advanced Earth Energy Budget Monitoring System – Operational									X																				
2021	Air Pollution Technology Satellite – Development									X	X				X										X					
2022	Stratospheric Monitoring System – Development									X	X														X					
2023	Stratospheric Monitoring System – Operational									X	X														X					

Table B-3 (Continued)
System/Objective Matrix: 2000 Series

System		Theme 1						Theme 2						Theme 3						Theme 4	Theme 7						Theme 11			
No.	Name	011	012	013	014	015	016	021	022	023	024	025	026	031	032	033	034	035	036	044	071	072	073	074	075	076	111	112	113	114
2024	Stratospheric Constituents Monitoring System – Development									X	X														X					
2025	Stratospheric Constituents Monitoring System – Operational									X	X														X					
2026	Sea Survey Technology Satellite									X			X										X							
2027	Sea Survey System – Development									X			X										X							
2028	Sea Survey System – Operational									X			X										X							
2029	High Resolution Sea Survey System – Development									X			X										X							
2030	High Resolution Sea Survey System – Operational									X			X										X							
2031	VISSR Atmospheric Sounder System – Development							X	X					X										X						
2032	VISSR Atmospheric Sounder System – Operational							X	X					X										X						
2033	Storm Satellite Survey System – Development							X	X					X										X						
2034	Storm Satellite Survey System – Operational							X	X					X										X						
2035	Synchronous Earth Observatory Survey System – Development							X	X					X										X						
2036	Synchronous Earth Observatory Survey System – Operational							X	X					X										X						
2037	Global Tropospheric Monitoring System – Development														X															
2038	Global Tropospheric Monitoring System – Operational														X															
2039	Regional Tropospheric Monitoring System – Development														X															
2040	Regional Tropospheric Monitoring System – Operational														X															
2041	Earthquake Prediction System – Development																	X				X								
2042	Earthquake Prediction System – Operational																	X				X								

Table B-3 (Continued)
System/Objective Matrix: 3000 Series

System		Theme 1						Theme 2						Theme 3						Theme 7					
No.	Name	011	012	013	014	015	016	021	022	023	024	025	026	031	032	033	034	035	036	071	072	073	074	075	076
3001	Global Wheat Prediction System – Development	X																							
3002	Global Wheat Prediction System – Operational	X																							
3003	Global All Crop Prediction System – Development	X																							
3004	Global All Crop Prediction System – Operational	X																							
3005	All Weather Global All Crop Prediction System – Development	X																							
3006	All Weather Global All Crop Prediction System – Operational	X																							
3007	Water Resource System I – Development		X																						
3008	Water Resource System I – Operational		X																						
3009	Watershed Runoff Forecast System – Development		X																						
3010	Watershed Runoff Forecast System – Operational		X																						
3011	Regional Water Balance Forecast System – Development		X																						
3012	Regional Water Balance Forecast System – Operational		X																						
3013	Surface Cover Change Detection System – Development			X																					
3014	Surface Cover Change Detection System – Operational			X																					
3015	Critical Environmental Area Monitoring System – Development			X																					
3016	Critical Environmental Area Monitoring System – Operational			X																					
3017	Land Capability System – Development			X																					
3018	Land Capability System – Operational			X																					
3019	Living Marine Resources System – Development				X																				
3020	Living Marine Resources System – Operational				X																				
3021	Broad Area Timber Inventory System – Development					X																			
3022	Broad Area Timber Inventory System – Operational					X																			
3023	Specific Area Timber Inventory System – Development					X																			
3024	Specific Area Timber Inventory System – Operational					X																			
3025	Range Forage Status System – Development						X																		
3026	Range Forage Status System – Operational						X																		
3027	Range Forage Prediction System – Development						X																		
3028	Range Forage Prediction System – Operational						X																		
3029	All Weather Range Forage System – Development						X																		
3030	All Weather Range Forage System – Operational						X																		

Table B-3 (Continued)
System/Objective Matrix: 3000 Series

System		Theme 1						Theme 2						Theme 3						Theme 4				Theme 7					
No.	Name	011	012	013	014	015	016	021	022	023	024	025	026	031	032	033	034	035	036	041	042	043	044	071	072	073	074	075	076
3031	Global Atmospheric Research Program System – Development							X																					
3032	Global Atmospheric Research Program System – Operational							X																					
3033	Post-GARP System – Development							X																					
3034	Post-GARP System – Operational							X																					
3035	Advanced Techniques Weather System – Development							X																					
3036	Advanced Techniques Weather System – Operational							X																					
3037	Weather Modification Experiments Monitoring System								X																				
3038	Climate Parametric Systems Study – Development									X																			
3039	Climate Parametric Systems Study – Operational									X																			
3040	Climate Forecasting System – Development									X																			
3041	Climate Forecasting System – Operational									X																			
3042	Stratospheric Parameter Experimental System – Development										X																		
3043	Preliminary Stratospheric Prediction System – Development										X																		
3044	Preliminary Stratospheric Prediction System – Operational										X																		
3045	"3 Dimensional" Stratospheric Prediction System – Development										X																		
3046	"3 Dimensional" Stratospheric Prediction System – Operational										X																		
3047	Water Quality Monitoring System – Development											X																	
3048	Water Quality Monitoring System – Operational											X																	
3049	Marine Parameter Experimental System – Development												X																
3050	Marine Forecasting System – Development												X																
3051	Marine Forecasting System – Operational												X																
3052	Extended Parameter Marine Forecasting System – Development												X																
3053	Extended Parameter Marine Forecasting System – Operational												X																

Table B-3 (Continued)
System/Objective Matrix: 3000 Series

System		Theme 1						Theme 2						Theme 3						Theme 4				Theme 7					
No.	Name	011	012	013	014	015	016	021	022	023	024	025	026	031	032	033	034	035	036	041	042	043	044	071	072	073	074	075	076
3054	Cyclonic Scale Severe Weather Predictions System – Development													X															
3055	Cyclonic Scale Severe Weather Prediction System – Operational													X															
3056	Thunderstorm Scale Severe Weather Prediction System – Development													X															
3057	Thunderstorm Scale Severe Weather Prediction System – Operational													X															
3058	Day-Night Severe Storm Prediction – Development													X															
3059	Day-Night Severe Storm Prediction – Operational													X															
3060	Tropospheric Parameter Experimental System														X														
3061	Global Air Pollution Analysis System – Development														X														
3062	Global Air Pollution Analysis System – Operational														X														
3063	Regional Air Pollution Prediction System – Development														X														
3064	Regional Air Pollution Prediction System – Operational														X														
3065	Hazard Warning System – Development															X													
3066	Hazard Warning System – Operational															X													
3067	Extended Hazard Warning System – Development															X													
3068	Extended Hazard Warning System – Operational															X													
3069	Disease Vectors System – Development																		X										
3070	Disease Vectors System – Operational																		X										
3071	Geological Mapping System – Development																						X						
3072	Geological Mapping System – Operational																						X						

Table B-3 (Continued)
System/Objective Matrix: 4000 Series

System		Theme 2						Theme 3						Theme 7						Theme 11				Theme 12				
No.	Name	021	022	023	024	025	026	031	032	033	034	035	036	071	072	073	074	075	076	111	112	113	114	121	122	123	124	125
4001	Earthquake Parameters – Development											X			X													
4002	Very Long Baseline Interferometry											X			X													
4003	Oceanographic Research			X												X						X						
4004	Low Atmospheric Research		X														X					X						
4005	Strato/Mesosphere Research			X	X													X			X	X						
4006	Synthesis of Living Matter in Labs																							X	X			
4007	Earth Fossil and Rock Analysis																			X	X		X	X	X	X		
4008	Lunar Sample Analysis																			X	X		X	X		X		
4009	Returned Solar System Sample Analysis																			X	X		X	X	X	X		
4010	Microwave Telescope – Extraterrestrial Life																									X		X
4011	Ionosphere-Magnetosphere Coupling Analysis													X			X	X	X									

Table B-4
System Synopses

1000 SERIES

1001. Global Positioning and Communication System – Development

This activity would include the development of a prototype communications satellite and its testing with the DOD Global Positioning System. It would also include any required modifications to the GPS from that presently planned, and the design and development of ground stations.

1002. Global Positioning and Communication System – Operational

This activity would involve the launching of additional communications satellites and implementation of ground stations to form the total operational network by 1985. This system would provide both positioning and communication services to larger ships and aircraft. Smaller craft could use beacons for position location but large antenna requirements would preclude use of the total system by such small craft.

1003. Expanded Coverage Comm. Navigation System – Development

In order to provide both communications and position-fixing data to small as well as large aircraft and spacecraft, a new communications satellite system with high power would be developed and tested by 1993.

1004. Expanded Coverage Comm. Navigation System – Development

The system developed above would be extended to an operational network to provide worldwide service at moderate costs.

1005. Advanced Techniques Comm. Navigation System – Development

It is projected that the use of advanced radio techniques such as short baseline interferometry might form the basis of an advanced communications-navigation system which would require only a few satellites rather than the numerous satellites required by the GPS technique. This system would involve such a development with a prototype launching in the late 1990's.

1006. Advanced Techniques Comm. Navigation System – Operational

By the year 2000, the prototype type satellite would be augmented to form an operational network requiring a total of only three satellites rather than twenty to thirty.

Table B-4 (Continued)

1007. Solar Power Technology

A ground based activity consisting of systems and economic analysis, and component and subsystem development which would support the development of a space solar power capability. A long term activity is envisaged to analyze the various system approaches such as photovoltaic and thermal, and to develop the solar energy conversion, and microwave conversion and transmission capabilities required. A significant transportation analysis and associated component/subsystem activity would be included in this activity.

1008. Solar Power Space Test Activity

A space test activity is required to develop and evaluate techniques which cannot be completely demonstrated on earth. This activity would be built around a Shuttle supported activity and gradually evolve into a permanent facility to support the assembly of prototype or operational stations. Initial tests with smaller than full scale systems would be directed towards the feasibility and efficiency of manufacturing and assembly operations, ionosphere effects, RFI, and high voltage testing. This activity would begin in the late 1970's with initial testing in the mid-80's and continued testing of optimized approaches into the 1990's. If the activity is confined to low earth orbit, the Shuttle can provide necessary transportation support. Testing at geosynchronous orbit would require additional transportation system development. The space test facility might be as large as a million pounds and incorporate habitability and construction capabilities in addition to the system itself.

1009. Solar Power Prototype – Development

This activity would assume a 1985-1990 decision to an operational activity with a prototype system as an intermediary step. The prototype activity would include the launch, assembly, and initial operation in geosynchronous orbit of a 2000-5000 megawatt solar power station intended to provide a final and realistic evaluation of the feasibility and economic viability of providing solar power via satellites. System activities would include the development of a large (1-2 million pounds to low earth orbit), launch vehicle, an orbital transfer logistics vehicle, and a manned orbital transfer vehicle. The power station would be the order of 25-50 million pounds and employ technologies and techniques developed in Systems 1007 and 1008. This system would be operable for testing in the early to mid-1990's.

1010. Solar Power System – Operational

This activity would result in the provision of solar power via satellite into the commercial system by the year 2000. The first space power station of a nominal 5000 megawatts might consist of the prototype described in System 1009 or a modification based on experience with that system. It would be expected that additional systems would be placed in space in succeeding years at a rate which would economically complement other energy sources.

1011. Power Relay Technology

A ground based activity consisting of system and economic analyses, and component and subsystem development which would support the development of a power relay capability. A long term activity is envisioned as an adjunct to System 1007 to emphasize those areas unique to the power relay concept, i.e., the passive reflection of microwave energy by an accurately oriented, long lived orbiting reflector.

1012. Power Relay Space Testing

A space test activity is required to develop and demonstrate techniques which cannot be completely demonstrated on earth. This activity would extend the activity of System 1008 to treat the particular requirements of the power relay concept.

Table B-4 (Continued)

1013. Power Relay Prototype Development

A space system which would be a continuously operating, on-line prototype to permit a complete evaluation of the system prior to operational multi-system commitment.

1014. Hazard Waste System – Development

During 1980-1990, development of low-cost, high-reliability system consisting of automated upper stages and abort-proof payload packaging for propelling radioactive wastes in half-ton quantities to earth- or solar-system escape. Simultaneous development and initial operation of pilot-scale concentration plants to permit realistic cost evaluation for the entire disposal process and an isolated launch site with an optimum down range safety situation.

1015. Hazard Waste System – Operational

Starting in 1990, continuous operation of waste-disposal system developed from the systems of System 1014, probably using automated Shuttle/special upper stages or heavy-lift launch systems. Routine operation of abort/retrieval/relaunch system for the small expected fraction of missions failing to eject the waste.

1016. Intentionally Left Blank

1017. Intentionally Left Blank

1018. Domestic Communications System – Development

Shuttle/Spacelab flights in 1980-85 would include component development tests for low-cost, high power domsats with large antenna elements and large traffic capacity including some privacy protection features. Development activity would also include launch of a prototype satellite weighing the order of one-half ton and including approximately 12-14 and 4-6 GHz transponders.

1019. Domestic Communications System – Operational

Starting in 1986 a series of satellites, of the types developed under System 1018, will be placed in service to meet U.S. domestic and foreign domestic requirements. These satellites are estimated to have a five year lifetime.

1020. Multi-Service Domestic Communications System – Development

System 1020 would consist of the development of an advanced satellite system having higher frequency links and longer lifetimes (7 years). A prototype would be launched in the early 1990's.

1021. Multi-Service Domestic Communications System – Operational

Starting in 1991 a series of satellites, of the type developed by System 1020 will be placed in service and required to meet increasing domestic and foreign requirements.

1022. International Communications System – Development

This activity represents a continuing development in international communications satellites. It is expected that this system would be tested in the mid- to late 80's. Advances would include higher power, multi-beam antenna and higher frequencies. A satellite lifetime of at least five years would be expected.

Table B-4 (Continued)

1023. International Communications System – Operational

This activity represents the operational augmentation of development effort of System 1022. Six to eight satellites, with appropriate spares would be required, to meet global requirements.

1024. Multi-Service International Communications System – Development

A continuing development and product improvement over System 1022 is projected in the 1990's. Satellite to satellite links would be developed and evaluated. Satellite lifetimes would reach seven years.

1025. Multi-Service International Communications System – Operational

Operational augmentation of System 1024. Global requirements would require of the order of twelve satellites, plus spares, by the end of the century.

1026. Personal Communications System – Development

Studies, economic analyses, and creation of a demand-test system to be evaluated in a selected U.S. area beginning in 1988 for a determination of the problems and prospects of personal communication including space links as part of the common carrier. Assessment of the technical and legal aspects of privacy-cost tradeoffs for such systems.

1027. Personal Communications System – Operational

Based on test marketing of System 1026, establishment starting in 1990 of a nationwide space-borne personal communications service. System would incorporate privacy protections found necessary by test and legal studies, and would operate using frequency allocations compatible with other U.S. interests such as radio astronomy.

1028. "Short-Term" Physical Chemical Research – Crew Operated

Experimental 50-kg to two-ton packages in spacelabs beginning in 1982 for fundamental experiments, e.g., catalytic chemistry, electrolysis, surface tension, thin films, capillarity, aerosols, foams, liquid dispersions, boiling, combustion and vapor deposition. Spacelab experiment packages operating for 7 to 30 days.

1029. "Long-Term" Physical Chemical Research – Crew Operated

Space-station experiments beginning in 1987 to explore longer-term (years) aspects of some of the phenomena explored in System 1028 and others, e.g. diffusion in polymers, expected to have longer-term unpredicted effects.

1030. "Short-Term" Low-g Material Science Research – Crew Operated

Continuation into mid-80's of experiments on solidification, purification, crystal growth, levitation, refining, etc., to advance knowledge and technology in materials science and to assess commercial potential of materials processing in space. 50-kg to one-ton spacelab experiment packages operating for 7 to 30 days in orbit. Shares certain equipment and facilities with Systems 1028 and 1033.

Table B-4 (Continued)

1031. "Long-Term" Low-g Material Science Research – Crew Operated

Space station experimental packages extending the capability to perform advanced experiments and pilot demonstrations over those in 1030. Program beginning in 1987. Shares certain equipment and facilities with systems 1029 and 1034.

1032. Commercial Processing – Crew Operated

Space-station adjunct special-purpose facility, perhaps 10,000 kg size, for routine processing of products found by Systems 1028-1031 to have space-processing economic advantage or uniqueness. Operation could start by 1987 if feasibility and desirability shown by then.

1033. "Short-Term" Biological Materials Research – Crew Operated

Continuation into mid-80's of experiments for biological materials and purification in earth orbit via 50-1000 kg experiment packages in spacelabs. Experiment durations 7-30 days in orbit.

1034. "Long-Term" Biological Materials Research – Crew Operated

Extension of System 1033 experiments and others from 30 days to one year with space station research facilities (1987-2000).

1035. Preliminary Effects of Gravity on Life – Crew Operated

Spacelab experimental packages for testing, starting 1981, of varying gravity (including zero g) on sample living systems. Short time of flights (7-30 days) will limit program to preliminary tests and equipment/technique development.

1036. Effects of Gravity on Life – Crew Operated

Long-term (months to years) testing of living systems in orbiting space stations, with experiments to measure gravitational effects. Test missions have already started (Skylab) and could resume by 1987 if associated support systems were created.

1037. Human Performance in Space – Development

Shuttle sortie and spacelab experiments beginning in 1981 to extend manned-flight experience to larger crew sizes, more diverse crew background/training/physical condition/sex combinations, and a greater variety of experimental and operational tasks than met in Apollo-Skylab experience. Share certain equipments and facilities with Systems 1035 and 1039.

1038. Human Performance in Space – Operational

Extension of System 1037 experiments into multi-person space station crews with orbit duty tours of several months, to evaluate additional physiological, medical, psychological and interpersonal factors bearing on more advanced manned missions. Space-station human testing could start by 1987 assuming station development. Share certain equipments and facilities with Systems 1036 and 1040.

Table B-4 (Continued)

1039. Preliminary Disease Processes Research – Crew Operated

Spacelab experimental packages designed for testing effects of space environments on diseases (e.g. cardiovascular) whose progress would be expected to be affected by gravity. Flights beginning in 1981; mission durations 7-30 days.

1040. Disease Processes Research – Crew Operated

Based on results of System 1039, clinical experimentation in Space Station for a wider variety of disease phenomena and longer durations (30 days to one year) in space. Assuming support systems provided, experiments could start by 1987.

1041. Magnetic Field Change Satellite

Three small satellites in polar orbits, each carrying a vector magnetometer, operating long enough (a few months) to map earth's entire field and show its typical short-term fluctuations. Measurement to be repeated every 5-7 years, either by new launch (Delta) or retrieval/relaunch (Shuttle).

1042. Magnetic Field Survey

Detailed magnetic survey by small satellite carrying magnetometer in low (250 km) earth orbit. Data to be correlated with ground geomagnetic observations, ionosphere observatory records, and solar patrol.

1043. Geodetic Satellites

Family of small Delta- or Shuttle-launched earth orbiters equipped for laser and/or radio VLBI tracking to determine ground station relative locations to 1 m and relative motions to 1 cm/yr. Data treatment and modeling to create a new dynamic geodetic network for entire earth by 1990.

1044. Gravitational Satellites

Earth orbiters equipped to measure varying acceleration due to non-uniformities in geopotential, and/or to measure local gravity gradients. Data treatment and modeling to permit creation of new geopotential maps with 3° x 3° surface resolution and 1-5 mgal magnitude accuracy by 1990.

1045. Atmospheric, Magnetospheric, and Plasmas in Space (AMPS) Crew Operated

Variety of equipment carried on Spacelabs or Space Stations. Approx. one mission per year 1981-1999; typical mission duration 7 to 30 days. Instrumentation to include both active (LIDAR, energetic-particle injection) and passive sensing experiments to investigate atmosphere-magnetosphere interactions and detail chemistry of the stratosphere and mesosphere.

1046. Atmospheric Neutral and Charged Particle Research

Orbital flight beginning in 1981 would continue measurement of composition and properties of the outer fringe of earth's atmosphere including variations in space and time, to provide evidence of physical and chemical kinetics.

Table B-4 (Continued)

1046. Atmospheric Neutral and Charged Particle Research (Continued)

Spacecraft, launched into low polar and equatorial orbits by Delta or Shuttle, carry photometers, spectrometers and charged-particle detectors. Mission duration two to five years.

1047. Electrodynamic Explorer

Spacecraft in low and highly-eccentric earth orbits with neutral and ion spectrometers, electric and magnetic field measuring instruments, and airglow photometers. Launch by Delta in 1980; after launches by Shuttle/IUS with recovery and relaunch; typical mission duration three years.

1048. Wide Field X-Ray and Gamma Ray

Large detector (3-m aperture) in earth orbit for general x-ray search; smaller collimated detectors for source location and identification; flare detector for varying objects. Multi-ton payload launched in 1984 by Shuttle, mission duration 3 years.

1049. 1 m UV Telescope

Telescope in earth orbit on Spacelab pallet with 1-m aperture, f/2.5 optics and detectors for wavelength range 900-3500 A. Scope to be used to study UV objects with a variety of instruments, e.g. polarimeters, spectrometers, image intensifiers. Mission durations one to four weeks (several during period 1982-90).

1050. 2.4 m Space Telescope

Telescope launched in 1982 by Shuttle/OMS, designed to achieve angular resolution 0″.1, instrumented for wavelengths 1150 A to 1 mm. Camera optics ranging from f/24 to f/500; spectrometers 1150-8000 A, spectral resolution 10^{-2} to 10^{-5} cryogenic IR detectors; photometers, polarimeters, astrometrics. Multi-ton free-flyer operating for two to four years between revisits.

1051. 5-6 m Space Telescope

Optical telescope designed to achieve 0″.02 angular resolution at 4000 A, instrumented for range 950 A -1 mm. Spectrometers, etc. would be advanced versions of those described for System 1050.

Launch of 25-ton free-flyer by heavy-lift vehicle or advanced Shuttle in 2005 for studies of the most distant parts of the universe.

1052. Small Submillimeter Receiver

Launch by Shuttle in 1981 of 5-10 cm aperture horn or telescope cooled to 20°K with detectors cooled to 2°K for broadband initial survey of the unexplored spectral region 0.2 to 10 mm, as precursor to System 1073. Experimental mission durations typically one week; experiment package mass about 100 kg.

1053. Infrared Interferometer

Michelson interferometer with two 3-m IR telescopes on a 30-m baseline, launched into earth orbit by Shuttle/Spacelab pallets in 1985, designed for wavelength range 0.01-2 mm (detectors cooled to 2°K), for resolving IR objects to fractions of a second of arc.

Spatial resolution 10^{-1} arc-seconds, sensitivity 1 jansky at 100μ, 0.1 jansky at 10μ. Mission durations (experimental) one to four weeks; (operational) several years with revisits.

Table B-4 (Continued)

1054. Large Cryogenic IR Telescope

Telescope in earth orbit, launched in 1984 and revisited annually thereafter by Shuttle; 1 to 1.5-m IR optics cooled to 2°K, with detectors, photometers, spectrometers designed for 1-1000 micron region; angular resolution to be diffraction-limited at 5μ, sensitivity in region 10^{-16} to 10^{-18} WHz$^{-1/2}$, to permit study of both compact and extended faint IR sources. Mission duration of six-ton free-flyer 5-6 years. Preliminary flights may be on Spacelab.

1055. Microwave LBI

A spacecraft in a highly eccentric orbit with 10-m aperture microwave telescope; launched by Shuttle in 1982 and operating as an interferometer in conjunction with two or more ground terminals to extend the VLBI concept to space baselines, resolve celestial sources to milli-arc seconds. Injected mass about four tons, mission duration 1-2 years are attached to Shuttle with multiple flights.

1056. High Energy Astrophysics Space Lab Cluster

Extreme ultraviolet, X-ray, and gamma-ray high-sensitivity fast-response detector package (effective apertures in 1 m to 2 m region) operable from spacelab pallet for short-time (one to four weeks) survey of known or suspected variable objects in coordination with airborne, and spacecraft observations by simpler instruments. Instrument cluster (with a mass of several tons) to be refitted with various types of instruments, improved, and reused on several Shuttle/Spacelab sortie flights over a period of 3 to 6 years beginning in 1980.

1057. Large Area Gamma-Ray Detector

Spacecraft in earth orbit carrying low- and high-energy gamma ray telescopes and scintillation detectors with effective apertures in the meter region, to measure energy distribution and flux of gamma rays in range 0.3 to 10^5 MeV. Multi-ton payload required by collimator, detector technique. Launch in 1984 by Shuttle; mission duration 8 years with spacecraft refurbishment.

1058. Low Energy Gamma Explorers

Small spacecraft with x-ray and gamma-ray instruments, launched by Delta or Shuttle in 1984-5 into low earth orbits to measure distributions of solar x- and gamma-rays in vicinity of earth, and to detect gamma-ray bursts, with time resolution in microseconds. Mission durations 1-4 years.

1059. Large X-Ray Telescope

Spacecraft with 2.2-meter grazing-incidence x-ray telescope and advanced detector package to determine spectra and polarization of x-rays from celestial sources. Launch in 1990 by Shuttle into earth orbit; mission duration 5-6 years.

1060. 1.2 Meter X-Ray Telescope

Multi-ton spacecraft with 1.2-m class Wolter and Baez telescopes and imaging detectors to measure x-rays with angular resolution 1.0 to 0.2 sec, spectrometers, and event detectors to permit observation of flare stars and other rapidly-varying sources in their active stages. Launch by Shuttle in 1982; mission duration 6 years with refurbishment.

Table B-4 (Continued)

1061. Heavy Cosmic Ray Detector

Spacecraft in earth orbit, launched by Shuttle and carrying instruments for measuring fluxes of high-energy cosmic ray particles and detecting antimatter events.

Multi-ton payload required by collimator and detector technique. Mission duration 3 to 9 years with spacecraft retrieval and refurbishment every few years.

1062. Relativity Experiments in Earth Orbit with Freely Spinning Gyroscope

Cryogenic gyro package launched by Delta or Shuttle in 1983 and remaining in orbit for a year or more, with gyro precession measured relative to stellar frame of reference to an accuracy of 0″.01/year.

1063. Gravity Wave Detector

Shuttle-launched (1986) half-ton free-flying experiment package containing two masses isolated from all known forces and a system for measuring their separation to one part in 10^{19}, with a data system searching for periodic changes in this separation over period region 0.1 to 10^{6} sec.

Mission duration 1-3 years.

1064. EOTVOS Effect Experiment

Quarter ton experiment package in Spacelab containing pairs of masses of different materials isolated from all except gravitational forces and torques. Measurement of relative accelerations of the bodies to one part in 10^{16}. Shuttle launch in 1985; mission duration 30 days.

1065. Stable Clock/Gyro in Solar Orbit

Two one-ton spacecraft in heliocentric orbits at high inclination with low (0.1AU) perihelion, with on-board clock stability of one part in 10^{-17} in 18 months, on-board cryogenic gyro drift 0″.01 per year for three years, and range measurement to 10^{-12}. Launch in 1992 by Shuttle plus high-energy upper stages; mission duration 3-5 years.

1066. Mercury Orbiter (W/Penetrometers)

Half-ton spacecraft sent into highly eccentric orbit of Mercury by Shuttle plus high-energy upper stages. Launch 1985, encounter 1986, end of mission 1987; extended tracking mission for relativity experiment is possible. Combination of imaging, geophysical and geochemical remote sensing instrumentation on orbiter; impacting penetrators to be delivered to planet's surface with simple geophysical/geochemical instruments.

Table B-4 (Continued)

1067. Interplanetary Near-Sun Probe

Launch in 1984 by Shuttle/IUS of a two-ton spacecraft incorporating solar-electric or solar-sailing propulsion and having environmental protection for close (0.1 AU) approach to sun. Instruments including particles and fields, solar plasma, solar wind, possibly solar x-ray detectors, and clock accurate to one part in 10^{17} over periods of one hour, with accurate dual frequency ranging.

1068. 700 Kilogram X-Ray Monitor

Spacecraft in earth orbit with 0.6 m soft x-ray telescope to map celestial x-ray sources to angular resolution 2 sec and determine approximate spectra of selected sources. Launch in 1981 Shuttle or Delta; mission duration 2-3 years.

1069. Solar System Escape Spacecraft

Small spacecraft with particles-and-fields instrumentation launched in 1980 by Titan-Centaur plus high-performance upper stages on a trajectory escaping solar system in general direction of solar apex. If mission launched in late 80's, electric propulsion, solar sailing, and/or Jupiter swingby could be used to reduce transit time to heliosphere boundary. Mission duration ten years or more.

1070. 10,000 kg Solar Observatories

Telescopes with apertures in meter range and a variety of instruments and high-capacity data link for high spatial, spectral and time resolution covering all wavelengths from IR to gamma rays, providing detailed (1 arc-sec) high-quality solar mapping in the visible and UV, and solar activity data, launched into earth orbit by Shuttle. Mission duration 5-10 years. For precursor descriptions see Systems 1075, 1077.

1071. Observatory in Solar Polar Orbit

Half-ton spacecraft launched in 1985 by Shuttle/IUS plus electric propulsion and/or Jupiter swingby to achieve polar heliocentric orbit. Instruments for solar/interplanetary fields and particles, cosmic rays, radio bursts, dust and plasma measurements as well as of x-ray and gamma-ray fluxes, and moderate resolution ultraviolet and visible imaging.

Mission duration 4-5 years.

1072. Large Ambient IR Telescope

Radiatively-cooled 3-m telescope launched in 1982 on spacelab and later as free-flyer, with detectors cooled to 2°K, designed for wavelength range 1-1000 microns, sensitivity 1 jansky/arc sec at 10μ. Telescope and instrument package mass about 3 tons; mission duration as free flyer, eight years with revisits; investigation of objects selected from the IR sky survey completed by System 1103.

1073. Submillimeter Telescope

Energy collector with effective aperture 10 m, with detectors and interferometers cooled to 2°K and designed for wavelength region 0.5 to 2 mm, to study celestial sources in this almost-totally unexplored spectral region.

Table B-4 (Continued)

1073. Submillimeter Telescope (Continued)

Launch by Shuttle in 1984; two-ton free-flyer with revisits, mission duration 4-6 years.

1074. Low Frequencies LBI

Two or three LF radio receivers in very high earth orbit, lunar orbit, or on moon; one terminal to have effective filled aperture (e.g. rhombic) 10 km; others dipoles. Baselines known to 3 m; system to produce high-resolution (fractions of arc sec) maps of radio sky. Launch of multi-ton payloads beginning in 1987 by Shuttle/IUS or Tug; mission duration 10 years.

1075. Spacelab Solar Telescope Cluster

A variety of solar observing packages launched into earth orbit on Spacelabs starting in 1981 and including a 1-m visible/UV telescope, an EUV telescope, and telescopes covering the solar x-ray spectrum.

After a series of one- to four-week spacelab sorties over a period of 3 to 4 years, the solar cluster can be integrated into a free-flying multi-ton solar observatory for continued observation of the sun over a decade or more.

1076. Solar Monitor

Small (50 kg) instrument package in earth orbit on spacelab pallets starting in 1981 and frequently thereafter through 2000. Instruments designed for broadband photometry in several spectral regions from 0.05 A to 30 microns, to record the various types of solar activity in conjunction with existing ground solar monitors and other climatological sensing systems.

1077. 1600 kg Solar Observatory

Spacecraft launched into earth by orbit by Delta in 1979, then refurbished, reinstrumented, and relaunched by Shuttle at two-year intervals, carrying fast-response multi-spectral (visible, UV, EUV, x-ray, gamma-ray) sensors to investigate flare phenomena and the response of earth's upper atmosphere to solar activity.

1078. Mercury Sample Return

Spacecraft sent to and from Mercury by highly advanced propulsion after launch by Shuttle or heavy-lift vehicle. Approximately 1 kg surface sample returned to earth about 2 years after 1999 launch. Technique would be similar to that of precursor System 1080 (MSSR), except for the much higher speed changes required.

1079. Venus Surface Sample Return

Spacecraft delivered to and from Venus surface by aerodynamic and aerostatic subsystems; approximately 1 kg Venus surface soil/rock sample and 20 liters Venus atmosphere sample collected and returned to earth. Launch in 1994 by Shuttle/Tug or heavy-lift vehicle; mission duration about 3 years.

Table B-4 (Continued)

1080. Mars Surface Sample Return

Multi-ton spacecraft launched from earth by Shuttle/Tug or heavy-lift vehicle in 1988. Descent to Mars and ascent with approx. 1 kg sample. Return stage to earth orbit. Sample biological quarantine protocol before descent into biosphere. End of mission 1991-2. Mission profile may include rendezvous in Mars orbit.

1081. Jupiter Atmospheric Probes

Entry probes delivered into Jupiter atmosphere in 1983 after launch of one-ton spacecraft by Titan/Centaur in 1980. Instrumentation to include mass spectrometry, particles-and-fields, and radio science. Data relay to orbiter from probe descending to approx. 10-bar pressure level in a few hours; orbiter mission then continuing for a few months with limited atmospheric (IR & UV) remote sensing and imaging.

1082. Saturn Atmospheric Probes

Entry probes delivered into Saturn atmosphere in 1986 after launch in 1984 by Shuttle/IUS/ upper stages. Instrumentation to include mass spectrometry, particles and fields and radio science. Data relay to fly-by bus during descent to few bars pressure level (1-2 hr); fly-by extended mission continuing for a few months.

1083. Titan Orbiter W/Penetrometer

One-ton spacecraft launched in 1992 by Shuttle/Tug/upper stages or heavy-lift vehicle. Insertion into Titan orbit 1996. Imaging, atmospheric, geochemical, and geophysical instrumentation. Entry/impact devices with simple chemical instrumentation to investigate lower atmosphere and, if possible, surface. Mission duration (penetrators) few hours to days; (orbiter) one year in orbit.

1084. Uranus Atmospheric Probe

Half-ton spacecraft launched by Shuttle/IUS/upper stages in 1984; Saturn swingby 1986; Uranus encounter 1989; end of mission 1990. Entry probe with mass spectrometer, particles and fields, and radio science instruments to descend to approx. 10-bar pressure level in a few hours, relaying data to flyby bus. Bus mission to then continue for a few months.

1085. Asteroid Sample Return

Launch in 1997 by Shuttle/Tug of a three-ton spacecraft incorporating solar-electric or nuclear-electric propulsion; asteroid (e.g. Flora) encounter 1998; 1-kg sample return to earth 2000. In-situ sample verification and selection by imaging and limited geochemical and mineral instrumentation.

1086. Comet Sample Return

Multi-ton spacecraft incorporating advanced (e.g. nuclear-electric) propulsion, launched in 2000 by advanced Shuttle/upper stages or by heavy-lift vehicle; comet rendezvous 2002, sample return (1 kg nuclear material, 50 liters coma gas/dust) to earth by 2006. (Mission description presumes rendezvous with nucleus to be practical; precursor Systems 1110 and 1111 may tell.)

Table B-4 (Continued)

1087. Venus Orbiter Imaging Radar w/Penetrometers

One-ton spacecraft delivered into low, circular, polar Venus orbit in 1983 by Shuttle/IUS plus spacecraft propulsion module. Coherent synthetic-aperture radar mapping of entire planet surface to resolution hundreds of meters, selected regions to tens of meters. Geophysical and geochemical instrumentation on penetrometers. Mission duration 1 year.

1088. Venus Lander

Half-ton spacecraft delivered to Venus surface in 1985 by Shuttle/IUS launch and entry/descent systems. Lander to include short-lived (approx. 3 days) subsystems with geochemical, e.g. gamma-ray spectrometer, instruments and macro- and micro-imaging. Lander also to carry small, low-powered, simply-instrumented (e.g. seismometer) package designed to operate at equilibrium in Venus surface environment. Mission of this subsystem to last about two years (one net year of visibility from earth).

1089. Lunar Sample Return (Highlands)

One-ton spacecraft landed on lunar highland, polar, or far-side regions with return rocket system to deliver approx. 1 kg sample to earth. Launch in 1988 by Shuttle/IUS; mission duration about 10 days.

Sample verification and selection with aid of on-board macro- and micro-imaging and geochemical instruments.

1090. Mars Polar Orbiter (W/Penetrometers)

Half-ton spacecraft launched by Atlas/Centaur, Titan/Centaur or possibly Shuttle/IUS in 1981. Encounter 1982; end of mission 1984. Spacecraft to carry orbital geochemical and geophysical remote sensing instrumentation plus entry packages with impacting penetrators having simple geophysical instruments.

1091. Jupiter Orbiters Spinning/3 Axis

Half-ton spacecraft delivered into Jupiter orbit by chemical spacecraft propulsion stage after launch by Titan/Centaur or Shuttle/IUS. Spacecraft to carry multispectral imaging, spectrometers, plasma and particles-and-fields instrumentation, and to have guidance and navigation making possible multiple encounters with the Jovian satellites. Launch in 1981; begin encounters 1984; end of mission 1987.

1092. Titan Lander

Three-ton spacecraft launched in 2000 by Shuttle/Tug/advanced propulsion systems or by heavy lift vehicle. Titan encounter 2005. Entry and descent in atmosphere; operation at surface with physiochemical instrumentation and imaging. Lander mission duration several months after landing.

1093. Uranus Orbiter

Two-ton spacecraft launched by Shuttle/Tug/advanced propulsion in 1995; insertion into Uranus orbit (with satellite encounters) in 2002; end of mission 2005.

Spacecraft instrumented with advanced low-light-level imaging and IR, UV multispectral remote sensing subsystems, magnetometry, and particles and fields.

Table B-4 (Continued)

1094. Asteroid Rendezvous W/Penetrometer Plus Laser

Three-ton spacecraft launched in 1987 by Shuttle/Tug/advanced upper stages; asteroid rendezvous 1989; end of mission 1990. Instrumentation to include instruments for geophysical, geochemical and mineral sensing, macro- and micro-imaging, for determining in-situ properties of asteriod surface.

1095. Mars Lander/Rover

Rover similar to lunar rover (System 1106), except lighter and more autonomous, launched to Mars in 1984 by Titan/Centaur or Shuttle/IUS. Rover instrumentation to include macro- and micro-imaging and limited geochemical/mineral geophysical instrumentation. Mission duration 1-2 years, roving path distance a few hundred km.

1096. Saturn Orbiter

Half-ton spacecraft delivered into Saturn orbit (with satellite encounters) in 1989 after 1986 launch by Shuttle/Tug/upper stages. Spectrometry, radio science, particles-and-fields, and imaging instrumentation. Mission duration (in orbit) four years.

1097. Neptune Orbiter

Two-ton spacecraft launched in 2000 by advanced Shuttle/upper stages or heavy-lift vehicle; Neptune orbit insertion (with satellite encounters) 2010; end of mission 2013.

Instrumentation to include spectrometry, particles and fields, and low-light-level multispectral remote sensing and imaging.

1098. Large Scale Microwave Telescope

Build-up beginning in the 1990's of an orbiting radio telescope with effective aperture kilometers in diameter possibly and a search system for detecting radio waves emitted by extraterrestrial intelligences. System to be used for very advanced radio astronomy and to serve as precursor for lunar far-side radio observatory.

Component launched by heavy-lift vehicle and by Shuttle, then assembled in orbit. Intended operating life 50 years or more; continued operation dependent on search results. See System 4010 for precursor project description.

1099. 200-1000 A UV Telescope

Telescope with 0.6 m aperture launched into earth orbit in 1984 by Shuttle. Spacecraft mass about one ton. Optics and detectors configured for extreme ultraviolet range, to obtain photometry, polarimetry, spectra and imagery of nearby hot celestial objects and to determine distributions of interstellar EUV extinction.

Mission duration 4 years.

Table B-4 (Continued)

1100. 400 kg UV Telescope Free Flyer

Various small spacecraft launched by Delta or Shuttle over period 1981-2001 into low or synchronous earth orbits, to investigate UV sources in wavelength range 1100-4000 A using optics in the 0.5-0.8 meter aperture class. Instruments would include Fourier spectrometers, polarimeters, photometers, and fast, high-resolution photon counters. Mission durations typically about one year.

1101. Wide Field UV Survey

Survey telescope (0.8 m, f/2) in earth orbit, instrumented for region 1000-3500 A and mapping UV sky in 5° x 5° fields to 3 sec. resolution and with sensitivity to 15-19 magnitude.

Launches aboard spacelabs beginning in 1981, mission durations one to four weeks until mapping completed (approximately 12 weeks total).

1102. Very Wide Field Optical Telescope

Small camera package (50 kg) with 12 cm, f/1 or faster optics mapping sky in 40° x 40° fields with spectral range 1000-8000 A to produce maps of galactic luminosity. Several flights aboard spacelabs beginning in 1980.

1103. Cryogenic IR Survey Satellite

Spacecraft in sun-synchronous polar orbit or low, low-inclination orbit, launched by Delta in 1979, carrying 0.6-m IR telescope with all optics and detectors cooled to 2°k to permit IR photometry, spectrometry and imaging in the 5-1500 micron region with excellent angular resolution and sensitivity 10^{-25} W m^{-2} Hz^{-1} and 100μ. Infrared map of the heavens to be completed in about one year.

1104. Lunar Polar Orbiter

Orbiters launched by Atlas/Centaur in 1980 into low polar and eccentric equatorial (radio relay) orbits to permit geochemical mapping of entire moon by gamma-ray spectrometry. Instrumentation to also include magnetometry, gravimetry, altimetry. Mission duration 2 years.

1105. Lunar Orbiter W/Penetrometer

Half-ton spacecraft launched into lunar orbit by Shuttle/IUS in 1983 and carrying, in addition to metric mapping and remote sensing instruments, a complement of impacting penetrators with simple geophysical (e.g. seismic) and geochemical instrumentation. Orbiter mission duration six months; penetrator mission duration one year.

1106. Lunar Rover Unmanned

One-ton mobile semi autonomous spacecraft landed on moon by Shuttle/IUS launch in 1988. Rover to carry macro- and micro-imaging, geophysical and geochemical instruments, and automation and data storage to permit operation for short periods out of earth line-of-sight, as required, e.g., for polar lunar base site survey. Total roving range 500-1000 km in one year of operation.

Table B-4 (Continued)

1107. Jupiter-Saturn Flyby

One-ton spacecraft launched in 1977 by Titan/Centaur; Jupiter encounter 1979; Saturn encounter (incl. Satellite Titan) 1983. Instrumentation includes spectrometry, radio science, particles-and-fields, and multispectral imaging.

1108. Uranus Flyby

Half-ton spacecraft launched by Titan/Centaur in 1979; Jupiter swingby 1981; Uranus encounter 1986; end of mission 1989. Bus instrumented with multispectral imaging, radio science, particles-and-fields, and spectrometry.

1109. Neptune Flyby

Half-ton spacecraft launched by Shuttle/advanced upper stages or heavy-lift vehicle in 1992; Jupiter swingby 1994; Neptune encounter 1999; end of mission 2000.

Instrumentation to include particles-and-fields, low-light-level multispectral atmospheric remote sensing, radio science and spectrometry.

1110. Comet Flyby/Fly-Through

Half-ton spacecraft launched by Titan/Centaur in 1980; Encke intercept 1980; end of mission 1981. Instrumentation to include fast imaging, UV, IR, mass spectrometry, dust detection and composition sensing, plasma, particles-and-fields.

1111. Comet Rendezvous

Two-ton spacecraft, incorporating solar-electric propulsion, launched by Titan/Centaur or Shuttle/IUS in 1981; Encke rendezvous 1984; end of mission 1985. Instrumentation to include imaging, mass spectrometry, dust and plasma analysis, particles-and-fields. Navigation to permit tour of coma and tail regions during active phase for a month or more near perihelion.

1112. 4 Person Near Earth Orbit Space Station

Shuttle-compatible station modules (14,000 kg, 4 x 15 m) experimentally assembled in earth orbit and manned continuously beginning in 1985.

1113. 12 Person Near Earth Orbit Space Station

Addition of modules to create full 12-crewmember, continuous-operation capability with advanced closed cycle subsystems (see Figure 9-5) and extension of duty tours of men and women to several months. Start of long duration physiology, medicine, biology and life-support system experiments. Operation continuing into 1990's.

1114. 12 Person Geosynch Space Station

Assuming trapped radiation hazard/shielding problem is met by adequate shielding, space station techniques from Systems 1112 and 1113 can be applied to permanent inhabited stations launched into geosynchronous orbits.

Table B-4 (Continued)

1115. 12 Person Lunar Base

A permanent lunar base could be established before 2000, perhaps at a lunar pole, with solar/nuclear power experimental agriculture, and a major astronomical observatory.

1116. Crew Operated Flight to Mars

After an unknown period for development and certification of solutions to physiological, propulsion, life-support, quarantine, etc., problems, an expedition to Mars (heavy lift vehicles, multiple launch, earth orbit mass 10^3 tons) would be possible. Then the unknown factor would become the national or international will to do it. Mission now considered improbable in the 20th century.

1117. Industrial Space Facility

Based on the results of Systems 1028-1038, and 1112-1113, a continuously-operating large-scale space processing facility in near earth orbit could be constructed for developing products for terrestrial use.

2000 SERIES

2001. High Resolution Visible-IR System – Development

Experimental one-ton spacecraft launched into earth orbit by Shuttle in 1982, instrumented with 7-channel multispectral scanners having 30-m resolution, programmed to cover world agricultural areas every few days and feeding data into an experimental crop-forecasting data network including agromet models and provisions for widespread comparison of predicted and actual yields. Precursor to System 3002.

2002. High Resolution Visible-IR System – Operational

This operational flight system would involve the use of satellites, orbits, and launch vehicles, as described in System 2001. A network of 2-6 of these satellites would be required depending upon the frequency of coverage required. A requirement for complete coverage every 9 days would involve as many as six satellites to allow for cloud cover problems. It is expected that the "Large Area Crop Experiment" will generate information pertinent to frequency of coverage requirements. Program planning would assume satellites with a three-year lifetime. Consequently, the first network would include the prototype described under System 2001, plus one to five additional satellites launched approximately one year later. Assuming a launch of the R&D satellite in 1981, and completion of the network in 1982, replacement networks would be required in the '84/'85 and '87/'88 time periods. These operational satellite networks would provide data to the following operational "ground" systems: 3002, 3008, 3014, 3012, 3026, 1017, 3070, and possibly 3039. Systems 3002 and 3026 would provide the driving requirements in relation to frequency of coverage.

2003. Very High Resolution Visible-IR System – Development

This R&D flight system represents an increased resolution capability over that described in System 2001. In addition to the 30 meter resolution, multi-spectral scanner, this system would include a very high resolution scanner system. This scanner system would be utilized on a selective or sampling basis to provide "ground truth" to be used in conjunction with the 30-meter system or to "capture" field sizes smaller than those amenable to

Table B-4 (Continued)

2003. Very High Resolution Visible-IR System – Development (Continued)

measurement with the earlier system. The satellite weight would increase to the order of 3000 pounds and the total uncompressed data rates, with both sensors operating, might be of the order of 500 mb/s. Orbits and launch vehicles would be similar to the 2001 system. This R&D "Flight" system will provide data to the following R&D "ground" systems: 3003, 3015, 3023, 3027, 1016, 3069, and possibly 3040.

2004. Very High Resolution Visible-IR System – Operational

This operational flight system would involve the use of satellites as described in System 2003. A network of 2-6 satellites would be required in the network depending upon frequency of forecast requirements and cloud coverage considerations. A lifetime of five years is estimated for this generation of satellites. The R&D satellite of System 2003 would be launched in 1990, and the remainder of the network in 1991. These satellites would be replaced in 1995/96. The "operational" satellite networks would provide data to the following "operational" ground system: 3004, 3016, 3024, 3028, 1017, 3070 and possibly 3041.

2005. All Weather Survey System – Development

This R&D flight system is directed towards reducing the cloud cover problems or limitations of Systems 2001 and 2003. In addition to the passive multispectral scanners, this system would include an active, multi-frequency, multipolarized microwave system. It would be used to augment the passive systems in cloud areas and possibly provide specialized data for particular applications in cloud-free areas. The satellite weight would increase to approximately 4000 pounds. It is not expected that data rates would necessarily increase, assuming all systems are not used simultaneously. Orbits and launch vehicles would be similar to those described for Systems 2001 and 2003, although a Shuttle with an "intermediate upper stage" would not place more than one satellite in the appropriate orbit. The R&D "flight" system will provide data to the following R&D "ground" systems: 3005, 3017, 3029, 1016, 3069 and possibly 3040.

2006. All Weather Survey System – Operational

This system is the operational counterpart of R&D System 2005. It is typified by a satellite network of only two satellites resulting from the alleviation of the cloud cover restrictions associated with earlier systems. A lifetime of five years is estimated for this generation of satellites. If the R&D satellite of System 2005 is launched in 1999, the second satellite to complete the operational network would be launched in the year 2000. This "operational" satellite network would provide data to the following "operational" ground systems: 3006, 3018, 3024, 3030, 1017, 3070 and possibly 3041.

2007. Long Wavelength Microwave System – Development

This activity involves the development of an automated satellite equipped with a passive microwave sensor, with one frequency in the 1.4 GHz range and employing an antenna of the order of 100 meters in diameter. Measurements from this sensor would support Systems 3003 (Soil Moisture), 3009 (Moisture Content of Snow), and 3019 (Salinity). An additional sensor would consist of a scanning spectrometer operating in the visible to infrared range to support System 3019 with water color measurements. This system development activity would be completed about 1985. The early 80's would involve the development of techniques for large antenna assembly, deployment, and placement using Shuttle capabilities and involving man to the degree required. The automated spacecraft resulting from this development activity would weigh on the order of 4000 pounds.

Table B-4 (Continued)

2008. Long Wavelength Microwave System – Operational

This system would be brought into operational use in the 1985-1990 time period based on the development activity of System 2007. At least two automated satellites would be required to support operational Systems 3004 and 3010 and development System 3019.

2009. High Resolution Long Wavelength Microwave System – Development

This development activity represents an extension of System 2007 activity and is intended to provide a higher spatial resolution capability using a larger antenna (~300 meters in diameter), optimized frequencies, and other improved techniques as available. The automated satellites would be larger, weighing on the order of 4000+ pounds. This development activity would complement the development Systems 3005, 3011 and 3019.

2010. High Resolution Long Wavelength Microwave System – Operational

This system would be brought into use in the 1990's based on the development activity of System 2009. The satellite network would consist approximately of four satellites, with the frequency of coverage being primarily dictated by the requirements of System 3020, Living Marine Resources.

2011. Weather Survey System I – Development

This development activity will extend from approximately 1978-85, and will result in an observation system to replace the TIROS-N and GEOS-D systems which will become operational in the 1978 time period. The Nimbus-F. R&D satellite will also contribute to the development activity. The system will include a capability to measure sea and air temperature every 12 hours on a 100 km grid. Winds will be measured using doppler radar and also by tracking free-floating balloons to obtain measurements on a grid of 200 km. Polar and sea ice will be measured every five days at a horizontal scale of 30 km. The GARP will constitute a major element of the R&D activity. The geosynchronous component of the system is described in System 2031. A specific prototype satellite will be launched as a part of this activity.

2012. Weather Survey System I – Operational

Implement in 1985 an operational system consisting of two to four satellites in sun synchronous, near polar orbits. The satellites will have the characteristics described in System 2011.

2013. Passive-Active Sensors, Large Scale Weather Survey System – Development

Extend the accuracy of the previous satellite system through the use of active near-infra sensors for the measurement of temperature and humidity profiles, and multi-frequency doppler system for wind measurements. Increase the horizontal grid scale from a 100 to 50 km's. The geosynchronous component of this system is described in System 2033.

2014. Passive-Active Sensors, Large Scale Weather Survey System – Operational

Implement the improved capability described above in a four-satellite network in the early 90's. This system will have basic sampling frequency of every six hours. Sensor complement will include a mixture of both passive and active sensors.

Table B-4 (Continued)

2015. Multi-Frequency Active Sensor, Large Scale Weather Survey System – Development

Continue the development of active sensors to provide greater accuracies.

2016. Multi-Frequency Active Sensor, Large Scale Weather Survey System – Operational

Implement, near the end of the century, those product improvements resulting from the development effort of System 2015.

2017. Earth Energy Budget Monitoring System – Development

Development and demonstration of an initial satellite to measure total solar flux, net radiation and cloudiness.

2018. Earth Energy Budget Measuring System – Operational

Implementation and operation of a 6/8 satellite network of the type of satellite developed in System 2017.

2019. Advanced Earth Energy Budget Monitoring System – Development

Development and demonstration of an advanced satellite, with capability to measure total solar flux at an accuracy of 2 vs 5 watts/square meter and net radiation at an accuracy of 5 vs 15 watts/square meter. A 10 channel vs 4 channel passive radiometer will be used. Spacecraft will be 3 axis stabilized.

2020. Advanced Earth Energy Budget Monitoring System – Operational

Implementation and operation of a 6/8 satellite network of the type of satellite developed in System 2019. Geographic distribution of measurements will be obtained.

2021. Air Pollution Technology Satellite – Development

Follow-on experimental satellites, or spacelab tests, to Nimbus G, employing a wider range of sensors of higher sensitivity, measuring both tropospheric and stratospheric constituents.

2022. Stratospheric Ozone Monitoring System – Development

A prototype for a first operational or continuous monitoring stratospheric satellite based on results of Nimbus G and System 2021.

Table B-4 (Continued)

2023. Stratospheric Ozone Monitoring System – Operational

Operational implementation of a network of satellites developed and demonstrated in System 2023.

2024. Stratospheric Constituents Monitoring System – Development

An advanced system as compared to System 2022 containing higher sensitivity instruments.

2025. Stratospheric Constituents Monitoring System – Operational

Operational implementation and use of a network of satellites developed and demonstrated in System 2024.

2026. Sea Survey Technology Satellite

Follow-on satellite to the presently planned "SEASAT" to provide additional R&D information for evaluation of sensors and to support model development.

2027. Sea Survey System – Development

Prototype satellite weighing 1- to 2-tons in polar orbit and containing a radar altimeter, microwave radiometer, scatterometer and imaging radar with data transmission to 15 mbps. System developed from SEASAT and System 2026 experience and flown in mid-80's.

2028. Sea Survey System – Operational

Prototype satellite of System 2027 augmented by three additional satellites to provide operational network.

2029. High Resolution Sea Survey System – Development

An advanced prototype satellite with performance targets as described in Systems 3052-3053.

2030. High Resolution Sea Survey System – Operational

Operational implementation of satellite network based on prototype developed and flight tested in System 2029.

2031. VISSR Atmospheric Sounder System – Development

This activity involves the development and demonstration of a synchronous satellite with instrument resolution capability more comparable with cyclonic scale (100 km) disturbances.

2032. VISSR Atmospheric Sounder System – Operational

Operational implementation and use of a 2/3 satellite network developed and demonstrated in System 2031.

Table B-4 (Continued)

2033. Storm Satellite Survey System – Development

Development and demonstration of a prototype satellite system with a resolution adequate for monitoring of tornado-producing thunderstorm scale phenomena e.g. 150cm telescope.

2034. Storm Satellite Survey System – Operational

Operational augmentation and use of satellite network developed in System 2033.

2035. Synchronous Earth Observatory Survey System – Development

Development and demonstration of a satellite system capable of both day and night (e.g. infrared) continuous monitoring of tornado-producing thunderstorm scale phenomena.

2036. Synchronous Earth Observatory Survey System – Operational

Operational augmentation and use of satellite network developed in System 2035.

2037. Global Tropospheric Monitoring System – Development

Prototype satellite flown in the late 1980's to demonstrate ability to measure tropospheric pollutants to operational accuracies. System evolved from experiments on Nimbus G and System 2021.

2038. Global Tropospheric Monitoring System – Operational

Operational augmentation of prototype satellite of System 2037 into an operational network to provide data inputs to regional pollution monitoring and management center.

2039. Regional Tropospheric Monitoring System – Development

Packages improved from System 2037 with possible addition of passive infrared heterodyne radiometer and laser absorption spectrometers, flown experimentally in mid-90's.

2040. Regional Tropospheric Monitoring System – Operational

Operational implementation of advanced satellite system demonstrated as System 2039.

2041. Earthquake Prediction System – Development

Using results of System 4001, an experimental limited area VLBI network would be established and its data provided to earthquake-forecasting centers. Starting about 1990 the forecasts would have enough background data for reliable comparison with experience.

Table B-4 (Continued)

2042. Earthquake Prediction System – Operational

Assuming success in System 2042, the limited network operation would become routine in the mid-90's and its principles could be extended to networks in other areas such as Alaska, Chile, Japan, and Turkey.

3000 SERIES

3001. Global Wheat Prediction System – Development

This system consists of two major elements. A wheat survey capability to provide the acreage planted and a prediction model or procedure to provide yield estimates for the acreage in a given area. The use of these two system elements provides a capability for production estimates of wheat. The LACIE (Large Area Crop Inventory Experiment) is directed toward the investigation and development of the two required system elements. LACIE will utilize data from ERTS satellite(s), pattern recognition techniques, and statistical sampling techniques to obtain the wheat acreage survey information. Agromet models will be used to provide yield estimates based on meteorological parameters. The initial models will be statistical in nature, employing data from curved ground networks and historical yield and weather data. The system envisioned in this study is a follow-on to the present LACIE effort. It will be designed to employ satellite data from System 2001 with its higher resolution and increased number of spectral signatures. Improved (factor of 20 in speed) pattern recognition, signature extension (geographic and environmental), and proportion estimate techniques will be included. The yield models will explicitly take into account plant growth phenomena, and meteorological satellite data. This development activity would be completed in the early 1980's.

3002. Global Wheat Prediction System – Operational

This system represents the operational implementation of R&D System 3001, and should be initiated in 1982. It will employ the network of satellites described in System 2002 to provide a global wheat production forecast as often as every two weeks.

3003. Global All Crop Prediction System – Development

This development will extend the wheat prediction capability to include all crops of major economic and/or food significance, such as rice, corn, and soybeans. This extension will involve the utilization of a higher resolution data gathering satellite system such as described in System 2003. This higher resolution is related to the need for dealing with smaller plot sizes associated with the non-wheat crops and/or an improved capability for training site selection or monitoring. Yield models will have to be developed for the additional crops. Whereas wheat yield is primarily dependent upon moisture and temperature, other crops are significantly dependent upon a greater number of variables. It would be intended that the "still important" soil moisture and temperature measurements would be provided by satellite System 2007. This development activity would be completed in the late 1980's.

3004. Global All Crop Prediction System – Operational

This system represents the operational implementation of R&D System 3003, and should be initiated in approximately 1990. It will employ the network of satellites described in Systems 2004 and 2008, and meteorological data with crop survey analyses and yield models to provide a global all crop production forecast as often as every two weeks.

Table B-4 (Continued)

3005. All Weather Global All Crop Prediction System – Development

Prediction Systems 3001 and 3003 utilize data from satellite Systems 2001 and 2003. These data are obtained with passive sensors operating in the visible and infrared regions of the spectrum. Cloud cover limits the ability to acquire data resulting in the need for networks of satellites (2-6) to obtain adequate frequency of coverage. Satellite System 2005 employs active microwave frequency sensors in addition to the passive sensors. The present prediction system (3005) represents the development of techniques for extracting crop survey and status information from the microwave sensors and integrating it with the passive data, so as to provide forecasts of equivalent accuracy with less frequency of data gathering. Yield models would employ microwave data on soil moisture and temperature from System 2005 and/or 2009. This development activity should be completed in the 1995-2000 time period.

3006. All Weather Global All Crop Prediction System – Operational

This system represents the operational implementation of R&D System 3005 and should be initiated before the year 2000. It will employ data from the network of satellites described in Systems 2006 and 2000, and meteorological data in conjunction with crop inventory analyses and yield models to provide global-all crop production forecasts as often as every two weeks.

3007. Water Resource System I – Development

This system involves the development of analytical techniques for the prediction of water availability resulting from snow melt in the western states. The analytical techniques would be initially developed using ERTS, with final development and evaluation involving the use of data from System 2001. These techniques would involve the repetitive mapping of the areal extent of snow cover coupled with in-situ, meteorological and historical measurements. The development activity would be completed in 1981.

3008. Water Resource System I – Operational

This operational system would be implemented in 1982 based on the techniques developed in System 3007 and employing data from the operational satellite network described in System 2002.

3009. Watershed Runoff Forecast System – Development

This system involves the development of models for the prediction of watershed runoff, optimizing the use of satellite measurements. Primary satellite data source would be from System 2007 to provide snow moisture content and soil moisture, augmented by meteorological satellite measurements and weather forecasts. This development activity would be completed about 1985.

3010. Watershed Runoff Forecast System – Operational

During the 1985-1990 time period, the development activity of System 3009 would be brought into operational utility in the western region of the country. This system would utilize the measurements from the satellite network described in System 2008.

3011. Regional Water Balance Forecast System – Development

This activity would represent an extension of System 3009 to the hydrologic modeling of the water balance of large areas. Satellite measurements would be provided by Systems 2009, 2015, and 2035.

Table B-4 (Continued)

3012. Regional Water Balance Forecast System – Operational

During the 1990's, development System 3011 would be implemented as an operational capability in the western United States using data from System 2010, 2016, and 2036.

3013. Surface Cover Change Detection System – Development

This system would be developed to support a large variety of federal, state, local, industrial and commercial users of satellite data and associated techniques. Primary uses would involve support of land use inventory and planning, environmental impact assessment, coastal zone and natural resource management. Development activity involves three elements: the satellites described in System 2001, techniques for applying the satellite data to the wide number of possibilities either separately or in conjunction with other sources of data, and the means for distributing the data and transferring the techniques in a convenient and timely manner. A number of distribution centers is envisioned, possibly one in each federal region in close proximity to existing technical groups of various federal agencies. The centers would be an outlet for satellite data, software to allow use of the data and integration with other data sources, and technical services to support use of data and software and to provide guidance as to the needs and availability of special purpose hardware to optimize satellite data use. The development of appropriately packaged techniques, analysis hardware equipment, and planning for the mode of operation of the regional centers would be completed by the early 1980's.

3014. Surface Cover Change Detection System – Operational

Beginning in 1982, the Federal Regional Centers would be implemented at a rate of one per year. Primary satellite data would be provided by System 2002.

3015. Critical Environmental Area Monitoring System – Development

The System 3014 capability would be extended to exploit the higher spatial resolution capability of satellite System 2003. This resolution would allow the rather detailed monitoring of selected critical environmental areas, in addition to the uses described previously. Necessary development would also be completed to allow direct receipt of regional data from the satellite systems. Regional centers would also be equipped to supply regional data from water and weather satellites.

3016. Critical Environmental Area Monitoring System – Operational

The capabilities described in System 3015 would be implemented in the various regional centers in the early 90's. Satellite data would be derived from Systems 2004, 2008, 3057, and 3034.

3017. Land Capability System – Development

The techniques developed in Systems 3013 and 3015 would be extended to develop analytical techniques for the estimation of land capability characteristics based on the optimized use of satellite data coupled with conventional sources of data. Such a capability would involve land use, surface cover, geological, hydrological, and weather-climate information. Such information would intend to provide an indication of the most efficient potential of the land from a natural and environmental standpoint. This system would involve the use of data from Systems 2005, 2009, 3058, 3035, 3063, and 2019. This activity would be completed by the year 2000.

Table B-4 (Continued)

3018. Land Capability System – Operational

The development activity of System 3017 would be implemented by the year 2000 in the various regional centers. The operational use of this system would involve data from Systems 2006, 2010, 3059, 3036, 3064, and 2020.

3019. Living Marine Resources System – Development

The initial activity in this area will require a significant advance in the understanding of biological-environmental relationships coupled with advances in techniques for the remote measurement of environmental parameters. Primary environmental parameters now under consideration include water temperature, salinity, water color, chlorophyll, and turbidity. This activity will involve the use of appropriately-equipped aircraft and experimental and operational spacecraft.

This experimental activity will be followed by the development and operation of prediction models related to the location and quantity of selected species. Primary satellite systems in support of this activity will be System 2007. The total fisheries management and assessment system will also require support of meteorological, communication, navigation and data relay satellites. This extensive and long term activity will continue into the mid-90's although limited operational capabilities to support fisheries activity are probable within this time period.

3020. Living Marine Resources System – Operational

By the year 2000, a capability for the assessment and management of at least one coastal species of major importance is envisioned. A coastal operational center for the activity is assumed with a capability to receive environmental information from Systems 2010, 2016, 2030 and 2036. Additional capabilities will be required for communication and navigation information as provided by System 1006. The forecasting center will be equipped with the necessary computing, model predictive software, data receiving and communication capability to interact with all fishing activities in the region of interest.

3021. Broad Area Timber Inventory System – Development

A timber inventory system to meet national requirements would be developed by 1982. It would involve the use of multi-stage sampling techniques with the source of data being satellite System 2001, aircraft measurements and limited ground measurements. Optimized sampling strategies, differentiation of species in mixed forest regions, and area demonstrations are required between now and 1982.

3022. Broad Area Timber Inventory System – Operational

The techniques developed in System 3021 would be transferred to the operating regions for use in the 1982-85 time period. Satellite data to support the operational inventory would be provided by System 2002.

3023. Specific Area Timber Inventory System – Development

This development activity represents an extension of System 3021 to exploit the increased spatial resolution capability of satellite System 2003 (multi-stage sampling techniques would be utilized). By 1990, a capability of specific timber ownerships would be demonstrated to support timber operations. The increased resolution capability would also provide a greater use (two stages) of satellite data in the national inventory.

Table B-4 (Continued)

3024. Specific Area Timber Inventory System – Operational

The techniques developed in System 3023 would be implemented operationally. Operational satellite System 2004 (and later System 2006) would support the activity. Software implementation would be at the regional, state and/or commercial operator level. Data receiving capability would be at least at the regional level as described in Systems 3013-3017.

3025. Range Forage Status System – Development

Utilizing data from System 2001 and selected ground truth, empirical vegetation models would be developed. Operation of these models would provide the near-real-time relative status or vegetation over the rangelands. Development work would be completed by 1982.

3026. Range Forage Status System – Operational

A regional forage data center would be established in the western U.S. starting in 1982, which would receive satellite data from System 2002. Based on these measurements, a bi-weekly vegetation status report would be issued for range areas. A primary requirement is timeliness and frequency of status reports.

3027. Range Forage Prediction System – Development

This activity would consist of the development of range forage predictive system. Modeling development would utilize vegetation cover and condition infomation from System 2003, soil and snow moisture from Systems 2007/2009, and meteorological data from Systems 2013 and 2033.

3028. Range Forage Prediction System – Operational

The forecasting capability developed in System 3027 would be operationally implemented in the forecasting center by about 1990.

3029. All Weather Range Forage System – Development

Satellite System 2005 employs active sensors to allow data acquisition with minimized cloud cover problems. This development activity would be involved in extending the analytical techniques of System 3027 to utilize these data.

3030. All Weather Range Forage System – Operational

The development activity described in System 3029 would be incorporated in the operational capability by 2000.

3031. Global Atmospheric Research Program System – Development

During the late 70's and early 80's, the GARP will be conducted to evaluate a worldwide, large scale, numerical weather forecasting system. The program will utilize the TIROS-N, GEOS-D, and Nimbus-F observation satellites (System 2011) to evaluate the predictive models. This activity will specifically support the development and evaluation of operational models and will utilize data from the prototype satellite of System 2011.

Table B-4 (Continued)

3032. Global Atmospheric Research Program System – Operational

This activity represents the operational implementation of System 3031. Satellite observations provided by System 2012.

3033. Post-GARP System – Development

This activity will include a further refinement of the numerical forecasting techniques developed in the GARP. These refinements may include boundary layer energy transfer, moisture convection and parameterized sub-grid phenomena. The sampling interval and grid size will be reduced to six hours and 50 km, respectively. Satellite observations are described in System 2013.

3034. Post-GARP System – Operational

Implement the results of the System 3033 development activity in the early 90's utilizing the operational satellite network described in System 2014.

3035. Advanced Techniques Weather System – Development

This development activity can only be defined at this time as a "product improvement" over earlier systems. Software modifications will be required to accommodate the greater use of active sensors envisioned in System 2015.

3036. Advanced Techniques Weather System – Operational

This activity involves the operational implementation of the developments of System 3035, and will utilize measurements from System 2016.

3037. Weather Modification Experiments Monitoring System

Meteorological satellite and related forecasting systems (3031-3036, 3054-3059, 2011-2016, 2031-2036) would be selectively used to support weather modification experiments to provide "before, during and after" information for planning and assessment. It is expected that the synchronous satellites would make a particular contribution to local or regional experiments particularly as their resolution capability increases. This activity involves no unique satellite systems, but it might require particular organizational and software arrangements to gain prompt access to all pertinent data required to support the experimental activities.

3038. Climate Parametric Systems Study – Development

An analytical and experimental effort to define the measurement systems required to develop a data base to support the evolution of a series of short and long range climate prediction models. The analytical effort of this system (3038) will be augmented by the efforts of Systems 4005 and 4003 related to the stratosphere and oceans, respectively. Experimental data will be provided by Systems 1076 (Solar Monitoring), 2017 (Earth Energy Budget), 2021, 2022 (Stratosphere and Troposphere Measurements), 2026, 2027 (Ocean Observations), 2007 (Soil and Snow Moisture, Sea Salinity) and 2011 ("low resolution" monitoring of meteorological parameters), and 2001 (Earth Surface Conditions, i.e., vegetation).

Table B-4 (Continued)

3039. Climate Parametric System Study – Operational

This activity represents the long term monitoring of climatically important parameters defined in System 3038, and the collection of this material in a form suitable for climatic research leading to the development of climate forecasting models. This data base which would be formalized by 1982 would contain appropriate data from Systems 1076 (Solar Monitoring), 2018 (Earth Energy Budget), 2023 (Stratosphere Monitoring), 2028 (Sea Surveys), 2002 (Earth Surface Conditions), and 2012 (Meteorological Parameters) and 2008 (Snow and Soil Moisture, Sea Salinity).

3040. Climate Forecasting System – Development

Based on the parametric studies of System 3039, the specific development of a climate forecasting system with operational utility would begin in about 1988. Satellite systems to support this development activity would include 1076 (Solar Monitoring), 2019 (Earth Energy Budget), 2024 (Stratospheric Monitoring), 2029 (Sea Surveys), 2003 (Earth Surface Conditions), 2009 (Soil and Snow Moisture), and 2013 (Meteorological Parameters). Systems 4005 and 4003 would continue to provide specialized research support.

3041. Climate Forecasting System – Operational

In the mid 1990's, an initial operational climate forecasting capability would be initiated based on the activity of System 3040. The extensive predictive modeling capability would use measurements from the following satellite systems: 1076 (Solar Monitoring), 2020 (Earth Energy Budget), 2025 (Stratospheric Monitoring), 2030 (Sea Surveys), 2004-2006 (Earth Surface Conditions), 2010 (Soil and Snow Moisture), and 2014 (Meteorological Parameters).

3042. Stratospheric Parameter Experimental System – Development

In the early 1980's the presently planned CO_2, ozone, and aerosol measurements would be continued and extended by Lower Atmospheric Composition and Temperature soundings to develop models and understanding of the impact of natural and man-made changes on the characteristics of the stratosphere. Sensor packages would be flown on spacelabs, free-flyers (System 2021), and as adjuncts to experimental and operational metsats.

3043. Preliminary Stratospheric Prediction System – Development

Assuming success in Systems 3042 and 2021, in 1985 stratospheric predictive models would be tested against continuing observations (System 2022), and the elements of a prototype operational system evaluated.

3044. Preliminary Stratospheric Prediction System – Operational

Implementation of a stratospheric monitoring system which would provide regular global surveys of the stratosphere and predictions based on models developed in System 3043.

Table B-4 (Continued)

3045. "3 Dimensional" Stratospheric Prediction System – Development

Through the use of passive (IR interferometry) and active (Lidar) sounders in 1985-90, predictive models would be developed experimentally and compared with experience on the effects of different vertical pollutant distributions in the atmosphere.

3046. "3 Dimensional" Stratospheric Prediction System – Operational

Assuming success in System 3045, the vertical-distribution sensors, models, and data systems would be added to the operational system of System 3044 and long-term effects of natural particulates and man-made pollutant distributions monitored worldwide starting in 1993.

3047. Water Quality Monitoring System – Development

Conduct a series of system analyses to assess the technical and economic viability of the use of in-situ sensors and relay satellites for water quality surveys. Support these analyses with a continuing in-situ instrument development program. Conduct demonstration tests for favorable regions and sensors.

3048. Water Quality Monitoring System – Operational

Based on results of System 3047, local and regional water quality survey systems would be established in the late 80's in those areas where it had proved feasible.

3049. Marine Parameter Experimental System – Development

This activity includes the analysis of data from System 2026 to evaluate sensor performance and the development of preliminary models for marine forecasting.

3050. Marine Forecasting System – Development

The preliminary models developed in System 3049 would be completed for deep ocean and coastal marine forecasting and evaluated in conjunction with the prototype satellite of System 2027. The sensor space network would build up to include four Shuttle-launched polar orbiting one- or two-ton spacecraft measuring sea state to 1 m, surface winds to ±20% of mean, ocean topography to 10 cm, and temperature to ±1°C.

3051 Marine Forecasting System – Operational

The prototype System 3050 would be augmented to provide an operational capability, including sea survey.

Table B-4 (Continued)

3052. Extended Parameter Marine Forecasting System – Development

Beginning in 1985 the measurement accuracies of System 3050 would be experimentally improved to target goals of: sea state ±30 cm, surface winds ±10% of mean, ocean topography ±1 cm, temperature ±1/2°C. The predictive models would be modified to accommodate the increased accuracies and greater data loads. These models would be evaluated utilizing data from prototype satellite System 2027.

3053. Extended Parameter Marine Forecasting System – Operational

The prototype System 3052 would be augmented to provide a more accurate global marine forecasting system in the 90's.

3054. Cyclonic Scale Severe Weather Predictions System – Development

This activity includes analyses of sensor performance from System 2301 and the development and evaluation of predictive models related to the occurrence, movement and/or severity of cyclonic scale (100 km) disturbances.

3055. Cyclonic Scale Severe Weather Prediction System – Operational

Implement an operational activity based on the development effort of System 3054 for improved monitoring and prediction of severe storms of 100 km scale or greater. The system would include a warning system based on earlier space projects and utilize observational data from System 2032.

3056. Thunderstorm Scale Severe Weather Prediction System – Development

Extend the development activity of System 3054 to include analyses of sensor performance from System 2033, and the development and evaluation of predictive models related to the accuracies, movement, and/or severity of tornado-producing thunderstorm scale phenomena.

3057. Thunderstorm Scale Severe Weather Prediction System – Operational

Implement an operational activity based on the development effort of System 3056 for improved monitoring and prediction of severe storm phenomena of the 30-50 km scale. System would include a warning system and utilize observations from System 2034.

3058. Day-Night Severe Storm Prediction – Development

Extend the development activity of System 3056 to include analyses of sensor performance from System 2035 (high resolution – day-night sensors) and modification of existing predictive models to incorporate this data to provide a continuous day-night capability of increased accuracy, and/or smaller scale phenomena.

3059. Day-Night Severe Storm Prediction – Operational

Implement an operational activity based on the development effort of System 3058, and utilizing observational data from System 2036. System would provide continuous day-night information through a warning system, using satellite relay where viable, and covering phenomena to a scale of 10 km.

Table B-4 (Continued)

3060. Tropospheric Parameter Experimental System

Analyze sensor performance of System 2021 as it pertains to the measurement of tropospheric pollutants. Initiate development of models for the prediction of pollutant trends in the troposphere.

3061. Global Air Pollution Analysis System – Development

This activity includes analysis of sensor performance data from System 2037 and the development of numerical models for predicting the movement and quantity of tropospheric pollutants including consideration of predictive meteorological conditions.

3062. Global Air Pollution Analysis System – Operational

Implement an operational activity based on the development effort of System 3061, utilizing observational data from System 2038. System would provide monitoring of global tropospheric pollutants and prediction of pollutant movement based on large scale atmospheric circulation conditions.

3063. Regional Air Pollution Prediction System – Development

This activity includes analysis of sensor performance from System 2039 and the development of predictive models for regional pollution conditions based on pollutant, meteorological, and topographic observations and conditions.

3064. Regional Air Pollution Prediction System – Operational

Implement an operational activity based on the development effort of System 3061, utilizing observational data from System 2040 to provide prediction of local/regional pollution conditions. System would provide basis for planning, management, or emergency actions at the regional level.

3065. Hazard Warning System – Development

Conduct a series of system analyses to assess the technical and economic viability of the use of in-situ sensors and relay satellites for a variety of measurements pertinent to impending hazards, e.g., forest fire indices, river stage level. Support these analyses with a continuing in-situ instrument and hazard prediction model development program. Conduct demonstration tests for favorable regions and sensors.

3066. Hazard Warning System – Operational

Based on System 3065 in-situ sensor networks, communication channels and software would be established in the most highly-benefited U.S. regions to provide an economical routine warning service.

Table B-4 (Continued)

3067. Extended Hazard Warning System – Development

Extend the development and analysis activity of System 3065 to a wider variety of conditions and geographical areas.

3068. Extended Hazard Warning System – Operational

Implement additional in-situ networks, communications, and hazard forecasting centers based on development efforts of System 3067.

3069. Disease Vectors System – Development

This activity involves the development of techniques for relating environmental data to the breeding and migration characteristics of harmful insects, the development of the capability to measure the environmental parameters remotely (or to relay environmental in-situ measurements), and the development of control techniques based on this information. Satellite Systems 2001, 2003, 2007, 2009, 2011, 2013, 2015, 2031, 2033, 2035 are likely sources of data to support the development of techniques. Specific measurement and technique development requirements will depend on problem selection. A continuing activity is envisioned.

3070. Disease Vectors System – Operational

This activity involves the operational implementation of the techniques developed in System 3069. The scope of the effort will depend upon the number, complexity, and geographical location of the problem. A large portion of this activity is expected to be outside the U.S. In these cases, U.S. involvement might vary from consultation to implementation of the system to operation of the system. The operational system would employ data from all or some of the following satellite Systems: 2002, 2004, 2008, 2010, 2012, 2014, 2016, 2032, 2034, and 2036.

3071. Geologic Mapping System – Development

This activity involves the development of the necessary techniques to optimally extract and portray geological information as made available by a series of satellite systems with increasing capability. Systems 2001 and 2003 would provide increased spatial resolution and spectral coverage over that provided by ERTS systems. System 2005 would provide active microwave sensors for obtaining data over normally cloud-covered areas, possibly providing some “vegation penetration” capability. The Shuttle system would provide a flexible capability for detailed measurements over particular areas of interest, and to provide variations in sun illumination conditions.

3072. Geologic Mapping System – Operational

This activity would involve the utilization of the techniques developed in System 1016 to prepare or update geological maps in selected areas of the world to provide information in direct support of mineral exploration. Data would be obtained from operational satellite systems 2002, 2004 and 2006.

Table B-4 (Continued)

4000 SERIES

4001. Earthquake Parameters – Development

Continuation into 80's of experiments using VLBI, laser multilateration, and seismology in combination to study earthquake mechanisms. Research would include use of both natural and man-made (orbital and lunar) VLBI radio signal sources, mostly provided incidentally to other programs.

4002. Very Long Baseline Interferometry

Network of ground stations including large (e.g. DSN) antennas and smaller portable antennas, with baselines spanning continents and oceans and straddling areas of active tectonic motions. Signals supplied by quasars, lunar radio transmitters, and earth satellites in high orbits. Data treatment and modeling to extract baselines to 1 m and relative motions to 1 cm/yr; also refinement of UT 1 (earth spin rate) and polar motion measurements by one order of magnitude from present values, by 1990. This system is a precursor to earth-moon VVLBI net.

4003. Oceanographic Research

An analytical and ground research activity utilizing a variety of statellite and other measurements to develop analytical tools and predictive models relating oceanographic parameters to the understanding and prediction of climate.

4004. Low Atmospheric Research

An analytical and ground research activity utilizing a variety of satellite and other measurements to develop an improved theoretical understanding of a number of atmospheric phenomena, e.g., frontogenesis.

4005. Strato/Mesosphere Research

An analytical and ground research activity utilizing a variety of satellite and other measurements to develop an improved theoretical understanding of conditions in the stratosphere and mesosphere and interactions between the two regions.

4006. Synthesis of Living Matter in Labs

(Date of achievement unknown.) Creation from non-living raw materials of energy-managing, information-transmitting, replicating molecular systems capable of building "negentropic" structures similar or identical to those produced by natural biological systems. If achieved, this would be further evidence for the universality of life and would greatly stimulate Systems 1098 and 4010.

Table B-4 (Continued)

4007. Earth Fossil and Rock Analysis

Continuation of searches for the earliest traces of pre-life and proto-life in ancient rocks on earth.

4008. Lunar Sample Analysis

Continuation of investigations on U.S. and Soviet lunar samples; extension to lunar bases (Systems 1113, 1115) when they become operational.

4009. Returned Solar System Sample Analysis

Age dating, isotopic, chemical, mineral, petrographic, and biological analysis of samples returned by Systems 1078, 1079, 1080, 1085, 1086. For quarantine reasons, initial investigations (early 90's) must occur in an Absolute Containment Facility.

4010. Microwave Telescope – Extraterrestrial Life

(Precursor to System 1098.) Development, via studies, pilot experiments, and build-up toward operational system, of receiving stations on earth capable of fast searches for accidental and/or intentional radio signals from other civilizations. Antenna apertures equivalent to tens of kilometers through use of arrays.

Initial experiments already in progress; dedicated project could start now; continuous full-capability search could be in progress before 2000 and could extend for 100 years or more, with uprating provided in 21st century by addition of orbital and lunar receiver sites.

4011. Ionosphere-Magnetosphere Coupling Analysis

This ground research and analysis activity utilizes the data from System 1045 and other systems in an attempt to develop an understanding of the energy interactions between the ionosphere and magnetosphere and how activity in these regions relates to the total energy transfer process between the sun and the earth.

APPENDIX C

TECHNICAL FEASIBILITY

The ability to achieve the objectives discussed in Chapter 5 depends upon the successful implementation of the systems described in Appendix B. Many of these objectives require technological advance, although in most cases it can be anticipated that the evolution of technology, in conjunction with normal program research and development, will support the introduction of the systems.

The relationships between specific systems and technology requirements are summarized as follows:

- Objectives associated with understanding, forecasting, and altering weather and climate phenomena are a major technological challenge. Successful development of analytical models to assist in understanding the interacting factors in these phenomena is a requirement for implementation of such systems as:

  3033 – Post-GARP System – Development
  3035 – Advanced Techniques Weather System – Development
  3037 – Weather Modification Experiments Monitoring System
  3038 – Climate Parametric Systems Study – Development
  3040 – Climate Forecasting System – Development
  3042 – Stratospheric Parameter Experimental System – Development
  4003 – Oceanographic Modeling
  4004 – Low Atmosphere Research
  4005 – Strato-Mesosphere Research

- Current limitations in transportation cost and lift capabilities, in low-cost solar conversion and space power systems, and the undeveloped ability to conduct extensive fabrication, assembly, and deployment of structures in Earth-orbit, limit the cost-competitiveness or the feasibility of:

  1007 – Solar Power Technology
  1009 – Solar Power Prototype – Development
  1114 – 12-Person Geosynch Space Station
  1115 – 12-Person Lunar Base
  1117 – Industrial Space Facility

- The ability to determine the electromagnetic wave signature of crops in various conditions and to model yields limits the effectiveness of:

  3003 – Global All-Crop Prediction System – Development
  3005 – All Weather All-Crop Prediction System – Development

- The ability to package, space-deploy, precisely point, maintain stability of, and control the attitude of large (1 to 2 km) reflector surfaces limits:

  1011 – Power Relay Satellite – Development

- The maintenance of structural integrity, stability, and ultra-high precision attitude control and pointing requirements (of the order of 0.01 to 0.05 seconds of arc), along with cryogenic cooling for detectors controlled to the diffraction limit is the pacing technology for:

  1051 – 5 to 6-M Space Telescope

- Limitations in our understanding of bone resorption, cardiovascular, and other physiological and psychological effects of low-duration weightlessness preclude committment to extended human operations in space significantly beyond that of the Skylab experience. Such effects are being studied and will be encountered through the experimentation of such systems as:

  1037 – Human Performance in Space – Development, and currently limit:
  1114 – 12-Person Geosynch Space Station
  1115 – 12-Person Lunar Base
  1116 – Crew-operated Flight to Mars
  1117 – Industrial Space Facility

- The structural integrity of 30-meter infrared interferometers with baseline measurements to 1 to 2 mm and stability to 0.01 rms seconds-of-arc limits:

  1053 – Infrared Interferometer

- Our current ability to quarantine, control, and preclude back contamination from return surface samples is the pacing technology for the implementation of:

  1078 – Venus Surface Sample Return
  1080 – Mars Surface Sample Return
  1085 – Asteroid Sample Return
  1086 – Comet Sample Return

- Advances in extreme environment survivability are required for:

  1066 – Mercury Orbiter (w/Penetrators)
  1067 – Interplanetary Near-Sun Probe
  1078 – Mercury Sample Return
  1079 – Venus Surface Sample Return
  1088 – Venus Lander

- Nuclear electric propulsion, or solar electric propulsion, is required for:

  1066 – Mercury Orbiter (w/Penetrators)
  1067 – Interplanetary Near-Sun Probe
  1071 – Observatory in Solar Polar Orbit

1078 – Mercury Sample Return
1083 – Titan Orbiter (w/Penetrator)
1085 – Asteroid Sample Return
1086 – Comet Sample Return
1092 – Titan Lander
1093 – Uranus Orbiter
1096 – Saturn Orbiter
1097 – Neptune Orbiter
1111 – Comet Rendezvous

- Our ability to search for extraterrestrial intelligent life by means of large arrayed antennas is currently limited by the cost which in turn is dependent upon major advances in increased sensitivity and large phased array discrimination.

- Advancement in the autonomy of remote vehicles and spacecraft is needed to implement:

  1079 – Venus Surface Sample Return
  1080 – Mars Surface Sample Return
  1085 – Asteroid Sample Return
  1086 – Comet Sample Return
  1092 – Titan Lander
  1095 – Mars Lander/Rover
  1096 – Saturn Orbiter
  1106 – Lunar Rover Unmanned
  1111 – Comet Rendezvous

- The design, deployment, and possible scanning of a 100 to 300 meter antenna with associated vehicle attitude control and stabilization limits is required for:

  2007 – Long Wavelength Passive Microwave System – Development
  2009 – High Resolution Long Wavelength Passive Microwave System – Development

- Structural integrity, stability, and attitude control and pointing abilities limit:

  1052 – 2.4 M Space Telescope
  1054 – Large Cryogenic IR Telescope
  1073 – Submillimeter Telescope
  1075 – Crew-operated Solar Telescope Cluster
  1098 – Large-scale Microwave Telescope

- The advancement of high-power, multi-beam satellite technology and large ground data processing systems for traffic surveillance limit the implementation of:

  1003 – Expanded Coverage Communications-Navigation System – Development

1005 – Advanced Techniques Communications-Navigation System – Development

- Determination of relative contributions to earthquake prediction model of, and accurate measurement of rock dilatency, Earth crustal distortion on a global and regional basis, Earth's rotational rate, and Earth's crustal wobble are necessary for successful implementation and utilization of:

  2041 – Earthquake Prediction System – Development
  4001 – Earthquake Parameters – Development
  4002 – Very-Long-Baseline Interferometry

- Fail-safe abort systems, economical waste separation and packaging, and low-cost space transportation to Earth-orbit pace the successful implementation of:

  1014 – Hazard Waste System – Development

- Technology advances in activities associated with suitable tissue culture – cell separation space facilities, the delivering of and maintaining of uncontaminated cultures in viable condition, and electropheresis equipment pace:

  1033 – "Short-term" Biological Research – Crew-operated
  1034 – "Long-term" Biological Research – Crew-operated
  1034a – Commercial Biological Processing – Crew-operated

- The need to develop data links for hundreds of megabits per second is a pacing technology for:

  3003 – Global All-crop Prediction System – Development
  3005 – All-weather Global All-crop Prediction System – Development

- End-to-end data management including specialized high resolution sensor development, general flight and ground instrumentation, system for timely data distribution to ground users, adequate mathematical models, and numerical computation techniques to perform analyses variously limit our ability to implement:

  2011 – Weather Survey System I – Development
  2013 – Passive-active Sensors Large-scale Weather System – Development
  2015 – Multifrequency Active Sensor Large-scale Weather System – Development
  2021 – Air Pollution Detection System – Development
  2022 – Stratospheric Ozone Monitoring System – Development
  2024 – Stratospheric Constituents Monitoring System – Development
  2027 – Sea Survey System – Development
  2029 – High Resolution Sea Survey System – Development
  2031 – VISSR Atmospheric Sounder System – Development
  2033 – Storm Satellite Survey System – Development

2035 – Synchronous Earth Observatory Survey System – Development
2037 – Global Tropospheric Monitoring System – Development
2039 – Regional Tropospheric Monitoring System – Development
3013 – Surface Cover Change Detection System – Development
3015 – Critical Environmental Area Monitoring System – Development
3017 – Land Capability System – Development
3031 – Global Atmospheric Research Program Support System – Development
3033 – Post-Global Atmospheric Research Program System – Development
3035 – Advanced Techniques Weather System – Development
3038 – Climate Parametric System Study – Development
3040 – Climate Forecasting System – Development
3042 – Stratospheric Parameter Experimental System – Development
3043 – Preliminary Stratospheric Prediction System – Development
3045 – "3-Dimensional" Stratospheric Prediction System – Development
3054 – Cyclonic Scale Severe Weather Prediction System – Development
3056 – Thunderstorm Scale Severe Weather Prediction System – Development
3058 – Day-Night Sensor Weather Prediction – Development
3061 – Global Air Pollution Analysis System – Development
3063 – Regional Air Pollution Prediction System – Development
3065 – Hazard Warning System – Development
3067 – Extended Hazard Warning System – Development

- The technology associated with imaging radar, which requires extensive onboard data processing and adaptive spacecraft telemetry techniques, requires advancement in order to implement:

2027 – Sea Survey System – Development
2029 – High Resolution Sea Survey System – Development
3049 – Marine Parameter Experimental System – Development
3050 – Marine Forecasting System – Development
3052 – Extended Parameter Marine Forecasting System – Development

- The following systems have unique sensor development requirements:

1056 – High-energy Astrophysics
1057 – Large-area Gamma-ray Detector
1061 – Heavy Cosmic-ray Detector
1063 – Gravity Wave Detector
1064 – Eotvos Effect Experiment
1068 – 700-Kilogram X-ray Monitor
1100 – 400-Kg UV Telescope
1101 – Wide Field UV Survey

In addition to the technological requirements considered above, space transportation must be considered more extensively (see Chapter 9).

NASA-Langley, 1976