AEROSPACE REPORT NO.
ATR-76(7365)-1, VOL. II

DRA

Advanced Space System Concepts and Their Orbital Support Needs (1980—2000)

Volume II: Final Report

(Study of the Commonality of Space Vehicle Applications to Future National Needs)

(UNCLASSIFIED VERSION)

Prepared by
I. BEKEY, H. L. MAYER, and M. G. WOLFE
Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

April 1976

Prepared for
OFFICE OF SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

Contract No. NASW 2727

Systems Engineering Operations
THE AEROSPACE CORPORATION

(NASA-CR-148703) ADVANCED SPACE SYSTEM CONCEPTS AND THEIR ORBITAL SUPPORT NEEDS (1980 - 2000). VOLUME 2: FINAL REPORT (Aerospace Corp., El Segundo, Calif.) 188 p HC $7.50 CSCL 22A

N76-30245

Unclas
G3/12 15344

Aerospace Report No.
ATR-76(7365)-1 Vol. II

ADVANCED SPACE SYSTEM CONCEPTS AND THEIR ORBITAL SUPPORT NEEDS (1980-2000)

(Study of the Commonality of Space Vehicle Applications to Future National Needs)

(UNCLASSIFIED VERSION)

VOLUME II: Final Report

Prepared by:

I. Bekey, H. L. Mayer, and M. G. Wolfe
Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

April 1976

Systems Engineering Operations
THE AEROSPACE CORPORATION
El Segundo, California 90245

Prepared for:

OFFICE OF SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW 2727

Report No.
ATR-76(7365)-1 Vol. II

ADVANCED SPACE SYSTEM CONCEPTS AND THEIR ORBITAL SUPPORT NEEDS (1980-2000)

(Study of the Commonality of Space Vehicle Applications to Future National Needs)

(UNCLASSIFIED VERSION)

VOLUME II: Final Report

Prepared by

I. Bekey
Study Director
Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

H. L. Mayer
Principal Staff Scientist
Advanced Programs Division

M. G. Wolfe
Staff Engineer
Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

Approved

R. H. Herndon
Group Director
Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

Samuel M. Tennant
General Manager
Advanced Orbital Systems Division
Systems Engineering Operations

FOREWORD

This report documents the results of Study 2.5, "Study of the Commonality of Space Vehicle Applications to Future National Needs," performed under NASA Contract NASW 2727, during Fiscal Years 1975 and 1976. Capt. R. F. Freitag and Mr. F. S. Roberts, Advanced Programs, Office of Space Flight, NASA Headquarters, provided technical direction during the course of the effort. The report is being issued in separate classified and unclassified versions.

The report is comprised of four separate volumes entitled:

Volume I	Executive Summary
Volume II	Final Report
Volume III	Detailed Data - Part I: Catalog of Initiatives, Functional Options; and Future Environments and Goals
Volume IV	Detailed Data - Part II: Program Plans and Common Support Needs

The first two volumes summarize the overall report. The third volume presents a catalog of the initiatives and functional system options; and thoughts on future environments and needs. The fourth volume matches the initiatives against the requirements and presents detailed data on alternate program plans for alternate future scenarios, from which likely needs for supporting vehicles and technology are derived.

This study was conducted independently from the Outlook for Space Study (OFS) partly because it was well underway at the time the OFS study began, and partly because the initial emphasis of the study was on likely future military space concepts and support requirements. An interim study report containing most of the material on initiative concepts and needs was made available to the OFS study team in February 1975, and the OFS interim results were made available to The Aerospace Corporation in June 1975. The exchange of reports did not result in significant changes to this study since the two studies emphasized different aspects of the space program, though a great deal of similarity in the future environments, goals, needs, and system support requirements is evident in their content.

The format chosen for this report follows approximately the briefing material evolved during the study, which has been widely presented. For this reason the reader may find some repetitions in a few sections of the text which attempt to present the data both in the context of the entire study and as reference data.

ABSTRACT

This report presents the results of a study which identifies over 100 new and highly capable space systems for the 1980-2000 time period: civilian systems which could bring benefits to large numbers of average citizens in everyday life, much enhance the kinds and levels of public services, increase the economic motivation for industrial investment in space, expand scientific horizons; and, in the military area, systems which could materially alter current concepts of tactical and strategic engagements. The requirements for space transportation, orbital support, and technology for these systems are derived, and those requirements likely to be shared between NASA and the DoD in the time period identified.

The high leverage technologies for the time period are identified as very large microwave antennas and optics, high energy power subsystems, high precision and high power lasers, microelectronic circuit complexes and data processors, mosaic solid state sensing devices, and long-life cryogenic refrigerators. The very large antennas and optics could be constructed as rigid single structures, or utilize a new concept in self-adjusting phased arrays which was conceived during the course of the study. It envisions many independent coarsely stationkept sub-units, with adaptive phase control to achieve performance equivalent to that of single-structure antennas without the usual requirements for structural rigidity and attendant weight and thermal design problems.

Some important guiding principles for space system applications are derived: (1) the user equipment should dominate the total system design in concepts where there are very many, mobile, and untrained users. This will enable the user equipment to be small, inexpensive, simple, portable, convenient to operate, reliable, and provide services not otherwise possible to millions of users. In turn, this requires the satellite portion of the system to be highly capable and implies large size, complexity, and high cost. The

satellites could be in geostationary orbit, however, so that one or at most a few satellites would be required. Furthermore, the sum of the user equipment cost and satellite cost is minimized. (2) Large reflectors of relatively simple structure and in low orbit can provide a means for flexibly routing microwave or laser radiation between many points space-space, space-ground, or ground-ground around the earth for communication, surveillance, or power distribution applications. The low orbits find natural applications in international use. (3) Analog parallel processing combined with local fast digital processing of data in real time at sensor terminals, and versatile adaptive software control of the process should be employed. This will allow exploitation of the global coverage of space sensors, requiring only interpreted data without needless redundancy to be transmitted to the ground. This will in turn allow all-weather microwave links between space and ground, while permitting the space-to-space links to be optical and possess much higher bandwidth. (4) Large, complex, and probably expensive satellites and assemblies can benefit greatly from orbital assembly, initial adjustments and checkout, supply of consumables, servicing, and possible reuse. (5) Man may have an important role in space as a versatile self-programming tool in support of the above functions in addition to his role as researcher, explorer, intelligent observer, and decision maker.

Over 40 civilian and 60 military space system concept initiatives are identified representing a catalog of space opportunities for personal, civic, industrial, government, international, scientific, and military applications. Some of the initiatives have been previously suggested, however most were conceived during this study, particularly those which exploit bold forecasts of the likely advance of technology in the high leverage areas identified above. The results of preliminary calculations on size, weight, cost, and performance of each initiative are shown, as are their needs for transportation, orbital support, and technology.

A set of 42 program plans for seven different areas of civilian and military activity is derived by considering six alternate future world scenarios spanning the range from peaceful cooperation to nuclear war in the international environment, and from economic retrenchment to expansion in domestic attitudes. The supporting needs of each of these program plans for transportation to low earth orbit and for orbital transfer, orbital assembly and servicing vehicles, orbital support facilities, and advanced technology required are then obtained.

The supporting needs of the group of initiative concepts taken as a whole are presented. The requirements of the majority of systems can be fulfilled by the Space Shuttle, orbital transfer vehicles such as the Interim and Full Capability Tugs, and a Solar Electric Propulsion Stage; automated or manual orbital assembly and servicing stages; and orbital support facilities such as orbital assembly yards, warehouses, and research and development/test stations.

Most of the potential missions for the NASA and the DoD in the time period share the above support requirements for all the non-catastrophic world futures considered. Single development programs could therefore be expected to have common application.

The study also concludes that the great range of space capabilities represented by all the civilian system concepts identified, including the 40 newly cataloged initiatives as well as the programs in the 1973 NASA Mission Model, can be acquired with an average budget of less than five billion dollars a year through the year 2000.

ACKNOWLEDGMENTS

The study was performed for NASA under the direction of Mr. I. Bekey, Study Director and Assistant Group Director of the Advanced Mission Analysis Directorate.

The bulk of the innovative technological material was prepared by I. Bekey and Dr. H. Mayer jointly in a collaborative team effort. The material dealing with the future environments and goals was prepared primarily by Dr. H. Mayer. The programmatic material was prepared by Dr. M. Wolfe and I. Bekey jointly. The marshalling of other Aerospace Corporation resources including system weights estimation was performed by Dr. M. Wolfe. Cost estimation was aided by Mr. H. Campbell. The program evaluation algorithm and the extent of the spectrum of alternate world scenarios were provided by Dr. G. V. Nolde, consultant. Mrs. Janet Antrim provided invaluable and patient support in copy preparation and manuscript typing. The dedicated efforts of all participants are hereby gratefully acknowledged.

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

TABLES

FIGURES

FIGURES (cont.)

FIGURES (cont.)

FIGURES (cont.)

FIGURES (cont.)

1. INTRODUCTION

1.1 OBJECTIVES

The objectives of the study were to determine the likely system concepts which might be representative of NASA and DoD space programs in the 1980-2000 time period, and to determine the programs' likely needs for major space transportation vehicles, orbital support vehicles, and technology developments which could be shared by the military and civilian space establishments in that time period. Such needs could then be used by NASA as an input in determining the nature of its long-range development plan.

1.2 STUDY APPROACH

The approach used in this study was to develop a list of possible space system concepts ("initiatives") in parallel with a list of needs based on consideration of the likely environments and goals of the future. The two lists thus obtained represented what could be done, regardless of need; and what should be done, regardless of capability, respectively. A set of development program plans for space application concepts was then assembled, matching needs against capabilities; and the requirements of the space concepts for support vehicles, transportation, and technology were extracted. The process was pursued in parallel for likely military and civilian programs, and the common support needs thus identified. The approach is illustrated in Figure 1-1.

Initially the study was to emphasize the determination of support requirements for space application concepts, particularly for the military; however, as the study matured and innovative space concepts of great power were conceived, the study emphasis broadened to lend more balanced weight to the identification of the space system concepts themselves, and to civilian as well as military applications.

The midterm report, issued in March 1975, presented the collection of space concept initiatives based on the forecasted capabilities

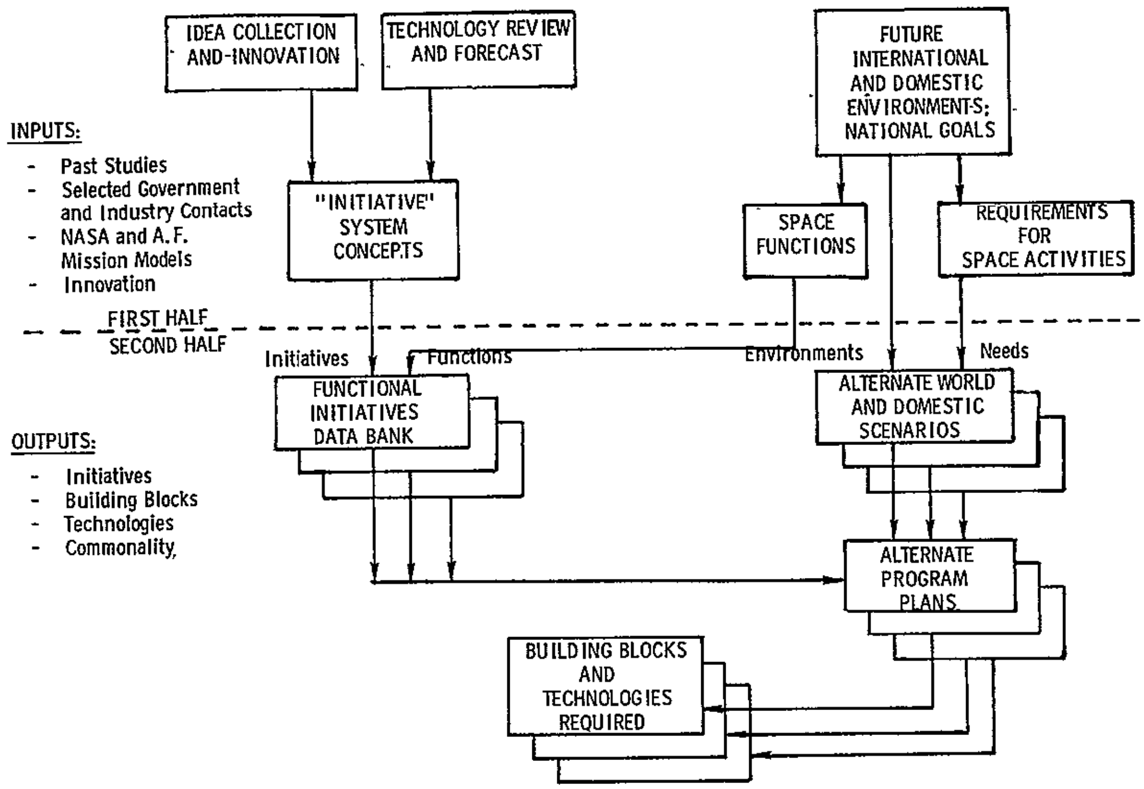


Figure 1-1. Study Approach

of technology in the 1980-2000 time period, and the collection of space functional needs based on consideration of the likely international and domestic environments. This final report includes that data, as well as the support needs of the space concepts, which were extracted from likely program plans.

1.3 GROUND RULES

1.3.1 Time Period

The time period covered in the investigation began in 1980, as it was unlikely that significant impact could be made on any program prior to that date; and concluded on or about the year 2000, since it was not likely that meaningful technology or need forecasts much beyond that date could be made.

1.3.2 Budgets, Policies, and Treaties

Constraints due to current or projected budgets, policies, treaties, and national goals were considered not necessarily valid in the process of synthesis of the system concepts and program plans in order to allow for treatment of alternate futures and consideration of all options.

1.3.3 Technology Advances

All technology advances that appeared possible (in areas in which the requisite phenomena had already been identified) were considered to be feasible in this study. Bold technology forecasts were encouraged; thus limitations due to the current funding of technology projects or number of skilled workers currently available in any one field were not considered valid for a 25-year projection. It was assumed that an overriding need for a space capability would result in appropriate budget and priority allocations, in training of the necessary work force if needed, and therefore extremely rapid progress compared to current rates could be made in most cases.

1.3.4 Viability of Concepts

The system concepts to be included in this study were to fall into the first two of the following classes though ideas corresponding to the third class were to be considered and documented. The first class consists of those concepts that are well understood and for which the status of technology permits confident definition of characteristics, performance, and cost; but which have not yet been adopted for reasons of requirements, policy, or politics (or have been rejected in the past). The second class consists of those that have no such history, but for which the technology is not as well understood permitting only gross sizing of apparently viable techniques. The third class contains those concepts whose function could be attractive and in which no law of physics is violated, however, no viable phenomena or techniques can yet be identified for their definition.

1.4 SOURCES

The study team gathered data for inclusion in the environment and system concepts portions of the work from past NASA and DoD planning studies, current NASA and Air Force mission models, and discussions with some key people in government, industry, and science. Appendix A of Volume III contains the list of people contacted.

The bulk of the innovative system concepts and the perspectives on utilization of space were developed by the study team during the course of the study.

The data in this report was developed independently from the NASA "Outlook for Space" Study, which ran concurrently.

1.5 NO ADVOCACY OR ENDORSEMENT

Though the starting points of the program planning in this study were the current and programmed space projects, the projection of future capabilities and needs was performed by the authors without official input by any element of the NASA or DoD. Furthermore, even though some of the material presented may well be reasonable or representative of actual NASA or DoD planning, no official or unofficial NASA or DoD endorsement is implied of the material contained herein. The thoughts are solely the views of the authors.

The system concepts and their technological base are presented with no evaluation of the relative mertis of space versus terrestrial approaches, and indeed, no value judgment that any one concept or group of concepts is "better" than any other. None of the individual system concepts shown herein are advocated per se, as they are intended to serve as examples of what could be done, and may well vary in significant detail or numbers from other embodiments of similar principles. However, the perspectives of space application and insights on how to operate in space through the close of this century, as well as the serious consideration of the collective space capabilities of some group of space system concepts (such as the ones identified herein) is recommended by the authors.

GUIDING PRINCIPLES FOR SPACE UTILIZATION

2. GUIDING PRINCIPLES FOR SPACE UTILIZATION

This section provides some insights into principles which should be used to guide space utilization for the rest of this century. These principles were derived from past experience in the application of space programs, an overview of the group of initiative concepts as presented in Section 4, and feedback from presentation of the material to key people. The discussion is summarized in Table 2-1.

2.1 COMING MATURITY OF SPACE CAPABILITIES

The Space Age is now almost twenty years old. In this period, the space program was, to a large extent, technologically limited and our imagination far outdistanced our technological capabilities. The payload capability of most boosters was relatively small and boost costs were high, which, coupled with the requirements for assurance of long unattended life in space led to sophisticated satellites which were constructed with minimum weight at the expense of higher cost. Initially much of the space activity was oriented toward research, exploration, testing of techniques and concepts, and demonstration of capability rather than toward day-in and day-out operations for economic payoff, rendering services, or making the military security of the country dependent on space. It was only in the last 5-10 years that the space program began transitioning into operational phases with systems such as communications, resources, weather, and certain military satellites, though except for commercial ventures in Comsats, the space systems were rarely expected to pay for themselves in direct revenues resulting from their use.

In marked contrast, the next twenty-five years of the Space Age, leading into the 21st century should see the technological maturation of the space program. The explosively expanding abilities of technology will supply a long and rich menu of potential space system opportunities, and wisdom and statesmanship will be needed to choose a restricted program

Table 2-1. Guiding Principles for Space Utilization

GENERAL

1. Exploit the large geometrical coverage.
2. Exploit the benign environment (except for the radiation belt altitudes).
3. Exploit the excellent transmission of energy and information.

APPLICATIONS

1. Extend utility of space to very many tiny, cheap, simple personal user sets by making satellites large, heavy, and complex.
2. Use passive reflectors in space for routing and directing information and energy over large ground distances. The sources and users can be on the ground, in the air, or in space.
3. Geostationary and other high altitude orbits best serve most domestic and some international applications, including large-scale observation, communications, energy delivery, tracking and control, readout and monitoring, and other applications in which constant coverage is desirable.
4. Low altitude multiple satellites best serve most applications where many widely separated nations wish to benefit from the same satellite and where intermittent contact is permissible, and applications where satellite proliferation is an aid in function.
5. In the far term, evolve the above operation functions into multi-functional satellites, some in low and some in high altitude orbits.
6. High value satellites may have to be protected.

SUPPORT

1. Assemble large and/or massive structures in orbit instead of lifting the entire structure on very heavy lift boosters. Fabricate low density structures in orbit to maximize utility of booster payload volume.
2. Service and repair satellites to allow simple, crude, inexpensive design and to extend useful life.
3. Build two classes of orbit-to-orbit transfer vehicles: slow but efficient unmanned stages with payload capacities into geo-stationary orbit equal to that of the Shuttle, and fast transfer manned vehicles to minimize radiation exposure.
4. In orbit, energy is free but mass expensive, having been lifted from the earth. Therefore, collect and reuse orbital mass whose function has been expended.
5. Consider primary roles for man to be assembly, initialization, repair, modification, and retirement of complex satellites, in addition to research, exploration, and command.
6. In the far term, evolve the support functions (assembly yards, warehouses, factories, research labs) into integrated orbital support facilities - some in low orbit, some in high orbit. Furnish mass, information, and energy to all satellites from such support bases.

from the options, balancing national priorities. In the civil area, economic considerations will become even more important as space activities in communication, navigation, earth resources and energy begin to significantly affect the economy and impact the structure of society. The average citizen will be markedly affected by the coming space services, and will in turn represent a cousumer demand. In international relations, space will provide a theater for beneficial cooperation, with practical economic as well as symbolic significance. In the military area, space systems could become so important as to force dependence on their capability.

Space exploitation at the close of this century will therefore be qualitatively so different from the space exploration and first applications of the third quarter, that past history cannot provide a reliable guide to the future. A far better guide is the nature of space itself, and the basic potentials and limitations of space science. In this section some of the essential features of the space environment are discussed, and then based upon these features, some insights are given into potential directions for evolution of meaningful capabilities.

2.2 CHARACTERISTICS OF SPACE

Space platforms naturally provide a large coverage view of earth. From synchronous orbits, communications and observation can be done with nearly hemispherical simultaneous coverage, while from close-in orbits with altitude a fraction of the earth's radius, whole earth coverage can be obtained within a number of periods approximately equal to the inverse of that fraction. Intrinsically space systems have long lifetimes, since orbits above a few hundred kilometers are relatively stable for years, and comparatively little propellant is required for minor orbit adjustments. Generally the space environment is quiet compared to that of earth, with low vibrations, low sonic, and low electromagnetic backgrounds, except for the radiation belts in which the background due to protons and electrons is high. Except in these belts, (and even within the belts if adequate shielding is used), precision measurements may eventually be more easily done in space than on the ground.

The near-zero "g" environment, and the very slow change in the gravitational potential with distance, will allow very large and very flimsy structures to be erected in space compared to those on the surface of the earth. Operational distances in space are characteristically large, but operational difficulties caused by such distances are minimized, due to both the unimpeded electromagnetic propagation in space, and the high characteristic velocity of objects in orbital motion.

Space activities in general do not produce any direct pollution on earth. Mass transport will always be a basic problem in space systems. For the near future, all the significant mass must come from the earth, and a large investment in energy is required to lift the mass into orbit. Energy transport, however, is in principle very easily accomplished in space, and an unlimited energy supply is available from the sun, awaiting only development of the technology to collect it in large amounts. Information can be transported over very long ranges on very small streams of energy or matter, and space with its excellent transmission characteristics and high view vantage is therefore preeminently suited for information flow.

2.3 APPLICATIONS FUNCTIONS

2.3.1 Large Satellites

The desirability of enabling very large numbers of average citizens and businessmen to directly and personally benefit from space requires that user equipment such as communication terminals be tiny, lightweight, portable, and above all inexpensive so as to become readily available to large numbers of potential users. This in turn requires the space systems serving such users to be large, heavy, complex, and probably expensive. However, since only one or a few satellites will be required, the total of satellite plus user equipment cost will be minimized with such a trade, and a host of services will be made possible by these principles which otherwise could not be available at any price.

Large antennas, high power, and microelectronic processors will be required for such "switching centers in the sky," in order to make up for the lack of power and antenna size in the user terminals, and in order to accommodate access by large numbers of users.

2.3.2 Passive Reflectors

The visibility coverage and lossless energy transmission characteristics of space can be exploited to construct large but simple passive reflectors in space, to route and direct energy in the form of microwave or laser beams. The energy would be distributed to users on the ground, airborne, or in space over considerable ground distances otherwise beyond the horizon. The energy could originate on the ground in the near term and in space in the far term. Such satellites could be conceived as "common carriers." Orbital reflecting or diffracting arrays with active or passive stabilization will be required.

2.3.3 High Altitude Orbits

Geostationary and other high altitude orbits have the characteristics of continuous visibility of a large portion of the globe. Satellites in such orbits find natural application to most communication, observation, energy delivery, readout and monitoring, tracking and control, and other related applications. The bulk of domestic services should therefore be met by satellites in such orbits, as the number is minimum: large satellites in high altitudes will enable such services, as described in 2.3.1.

2.3.4 Low Altitude Orbits

Satellites in low orbits move with respect to the earth's surface, and in general cover all portions of the globe. They consequently best serve applications where many nations wish to benefit from the orbiting of a given satellite, and where intermittent coverage is permissible. Examples include energy distribution and detail observations not possible from higher altitudes in the time period of interest due to technological limitations. Other applications include those where satellite proliferation and motion can aid the function.

2.3.5 Multifunction and High Value Satellites

Many of the applications for satellites share similar technological needs, subsystems, and even complete system configuration and architecture. As the capability evolves, many similar functions could be assigned to multifunction satellites to maximize the return on any investment. If development proceeds along this line, highly valuable national facilities will emerge, with the nation growing ever more dependent on their capabilities. Should this prove to be the case, some form of defense or survivability augmentation might be necessary even for purely civilian application satellites, due to the ready access of all to space.

2.4 SUPPORT FUNCTIONS

2.4.1 Assembly in Orbit

Very large and massive systems will be created on orbit by the assembly of pieces carried on several flights of transportation systems sized for much smaller payloads. Great flexibility will be evident, using manned or automated techniques, including the fabrication on orbit of very low density structures which cannot be packaged into a sufficiently large density to efficiently utilize booster payload bays. Assembly in low orbit as well as in high orbit might be required, resulting in different classes of orbit-to-orbit transfer vehicles. The Space Shuttle, the IUS, and some of their growth derivatives will comprise the first requisite for such capability to assemble in space.

2.4.2 Servicing in Orbit

Past space operations (and to a large extent current operations) have been severely constrained by mass limitations of boosters, and by the high cost of the spacecraft and the boosters. In the overall optimization of a concept, these factors have forced or favored highly sophisticated low mass spacecraft, resulting in high development and fabrication costs in order to attain viable performance over long unattended periods in space.

In the future, the advent of the Space Shuttle, follow-on space transportation components, and orbital support facilities will have a major impact. Lower transportation costs, combined with more liberal payload capacities, and the presence of man, will change the spacecraft optimization radically. Conservative and simple designs with conventional rather than exotic materials will be used liberally. Flight of "development or laboratory models" will become commonplace, as will the utilization and great redundancy of standardized components. This will be made possible by the requirements for shorter orbital life due to the adoption of routine maintenance on orbit.

2.4.3 Orbit-to-Orbit Transfer Vehicle

To provide for missions at high altitude and in synchronous orbit in the future, the two vehicle "shuttle-IUS/tug" concept of the present space transportation system should be extended, since it is more efficient in mass and energy use than is the single-vehicle-to-final-orbit concept. But frequently it will be an entire shuttle payload which is needed at high altitude, so that, contrary to some present designs, the orbital transfer vehicle capacity should match that of the shuttle. Except for special cases such as manned missions, the transfer from low to high orbit need not be fast, so that a large capacity vehicle could use low thrust but highly mass-efficient propulsion. A small fast vehicle could be used to take men and equipment that are sensitive to radiation effects rapidly through the radiation belts. Thus, both slow and fast orbital transfer vehicles will be needed.

2.4.4 Mass Use and Reuse

For effective mass management, a long-term schedule is needed of the requirements for mass in various orbits and of excess carrying capacity on launches. Dedicated or excess launch capability could be used to stockpile a series of storage yards in space with propellants and other expendables, and with structural materials needed in space assembly. But the largest stockpile of mass in space will be that in mission systems whose useful life is over. Provisions should be made for salvage and reuse of much of the material of these systems to utilize the investment in energy and skilled labor which went into them.

2.4.5 Roles of Man

Man has two sets of attributes which enable him to contribute effectively in space activities. One set is his vast information processing capability both sensory and intellectual. This ability can be well exploited by keeping man on the ground, but with an extension of his sensors and hands in space linked to him via an interactive data link. The second set is man's versatility both intellectually and mechanically. These attributes are best used by placing man physically on the scene in space to take care of unforeseen events, or infrequently expected processes which demand special automatic machinery or special software. In the future, therefore, as space operations become more ambitious, man should play an extended role on the scene working in fabrication and assembly facilities, in storage yards; checking out and initializing complex new space systems; supplying, repairing, modifying, and modernizing space equipment; and salvaging obsolete or inoperative space systems. Automated equipment should be used in conjunction at least to the extent that it frees man from routine, repetitive, or readily programmable tasks.

2.4.6 Integrated Support Facilities

Orbital facilities will be required to support the functions of fabrication, assembly, test, initialization, repair, reconfiguration, and retirement of complex satellites, as well as the more traditional roles of space research and exploration. While such functions might initially be provided by specific "space station" orientations, in the far term they could evolve into integrated multifunction orbital support facilities. Some such facilities would be needed near to clusters of geostationary satellites, and in several low altitude orbits in order to support the intended users with minimum expenditure of mass and energy. It is envisioned that all support to operating systems would be provided via such national support facilities.

ADVANCED
TECHNOLOGY

3. ADVANCED TECHNOLOGY

The next 25 years could bring an extremely rapid pace of advances in key areas of space technology. The impetus for the fast pace could originate from public demands for or acceptance of space capabilities which directly benefit large numbers of people, or provide economic justification of their own in the form of return to the investing capital. This section discusses the technologies which will be needed to apply the guiding principles of space utilization outlined in Section 2, as well as mentioned above.

A number of areas of technology were found to have particularly high leverage in permitting the conceptual design of space systems which meet the broad needs identified in Section 2 and in the treatment of anticipated goals and needs in the expected future environments treated in Volume III. These areas of high leverage technology are described in this section, and forecasts made of the technological capability likely to exist through the end of this century.

3.1 HIGH LEVERAGE AREAS

Almost all areas of technology will contribute to the future of the space program, although there are some areas which on consideration will have the highest leverage in enabling the construction of many types of space concepts with a great range of potential utility. These areas have been listed in Table 3-1, and are discussed below, beginning with those areas of technology utilized in this study for system synthesis.

3.1.1 Large Antenna and Optical Arrays

Space is a very benign medium from the standpoint of exerting only tiny forces on objects in orbit, thus making possible very large structures compared to those on the surface which have to withstand gravitational forces, weather, and winds. Very large antennas can be

PRECEDING PAGE BLANK NOT FILMED

Table 3-1. Technology Developments with High Potential for Space Applications 1980-2000

EXPLOITED IN STUDY

1. LARGE STRUCTURES OR ARRAYS IN SPACE
2. HIGH POWER, ENERGY
3. LASERS
4. ADVANCED COMPUTERS, ANALOG PARALLEL PROCESSORS
5. CHARGE-COUPLED-DEVICE SENSORS
6. LONG-LIFE CRYOGENIC REFRIGERATORS

NOT EXPLOITED IN STUDY BUT WORTHY OF CONSIDERATION

1. RADIATION ENGINEERING AT FREQUENCIES BETWEEN THE INFRARED AND MICRO-WAVE REGIONS
2. PLASMA PHYSICS APPLICATIONS
3. LASER-FUSION PROPULSION
4. COLLECTIVE MODE PARTICLE-ACCELERATORS
5. EXTREMELY LOW TEMPERATURE SOLID STATE PHENOMENA
6. HIGH INTENSITY SHORT PULSE MAGNETIC FIELDS
7. SURFACE CHEMISTRY
8. BIOLOGY

constructed by assembling modules brought up piecemeal, or even fabricating them in orbit. The structures can be extremely flimsy by earthbound standards and could even consist of widely separated elements, coarsely stationkept, but with finely controlled electronic properties so as to act as coherent portions of an antenna. Very large antennas have the property of large capture area or gain for communications with many tiny transmitters or receivers far away, as well as very narrow beamwidths which can be used to selectively communicate in preferred directions and to identify the direction to the source. Given the capability to assemble in space made possible by the Shuttle, there is no reason to presume that the size of today's antennas (tens of feet across) should in any way limit the size attainable in the next 25 years.

Large optical apertures are subject to similar reasoning. Their realization would enable the sensing of extremely weak sources at great distances, the narrow beamspread allowing the attainment of high resolution at long ranges or the long-range transmission of energy in very tightly collimated beams.

3.1.2 High Prime Power/Energy

Past space programs were limited in prime power generation to a few kilowatts (25 kW in Skylab), primarily due to the difficulty in lifting massive energy generation or conversion equipment. In the future, however, we need not be so restricted due to improvements in efficiency of generation as well as the advent of low-cost space transportation and the ability to assemble and service in orbit, and thus very large solar energy converters or very massive nuclear sources will become practical in space. Power levels measured in megawatts or gigawatts will be achievable by the year 2000. Such sources could power active sensors of unprecedented range or resolution, furnish energy to be transmitted through space with no attenuation for consumption elsewhere, and allow communication with very many small receivers far away.

3.1.3 Lasers

This area has developed primarily for terrestrial applications, but lasers are expected to rapidly find their way into the space program due to their ability to transmit coherent energy over long distances with very little beamspread using physically small apertures, and to capture most of it with small area receivers. Lasers will also make possible long-range, high-rate communications with complete freedom from intercept outside the beam; extremely accurate designation of tracking of optical aim points; high capacity and speed imaging and recording devices; coherent image processing; bulk terrestrial energy transfer through space using mirrors; and extremely accurate range, velocity, and angle measurements at long ranges. The ability to service in orbit will allow the arbitrary extension of operating life, rendering economic feasibility to the use of lasers of any size or power.

3.1.4 Microelectronic Computers and Processors

The safest forecast of any in this report is that the impact of microelectronics, with its large-scale integration of components on tiny semiconductor "chips," will be nothing short of revolutionary. Data processing power and speed per unit size, weight, and cost of the package will increase dramatically. Complex computations, central vehicle control, data reduction, data compression, image reconstruction, and self-generation and programming of software will be readily performed anywhere. For these reasons, all computing tasks logically best done in space will be performed there, rather than following the past practice of piping as much as possible to the ground for ground computation. The massive use of information processing will be central to most advanced space concepts, and through fault-tolerant designs, self-checking features, and servicing in orbit will be among the most reliable of all spacecraft functions. This will allow the use of space for switching and routing of very many terrestrial signals, addressor and addressee recognition, interference reduction, and many other information processing functions. Indeed, such advanced information processing will enable the realization of many of the other areas of technology.

3.1.5 Solid-State Sensors and Analog-Parallel Processors

Unprecedented sensor element densities in two-dimensional mosaics of extremely large numbers of detectors will be possible using the relatively new techniques of charge coupling for readout or shifting. These charge-complex or charge-injection devices could be used alone or coupled to similar mosaics of processor elements for sensor-specific data processing. Such devices will make possible tiny, lightweight sensors capable of high resolution simultaneously with high spatial area coverage per unit time, combinations of features currently not possible. Sensitivities to near the quantum limit will be available for almost any wavelength of interest, and integration of signals in preferred directions will allow the detection of very tiny amounts of source energy. These devices, closely coupled to powerful central processors as described in 3.1.4, will revolutionize the sensing ability from space, allowing space to be used for large-scale information gathering, processing, and dissemination.

3.1.6 Cryogenic Refrigerators

Various advanced sensing devices and optical components must be cooled to temperatures low enough that their internal noise becomes insignificant compared to external or source-generated noise. With such refrigerators, space sensors operating at wavelengths in the long wave or far infrared will become practical, as will cooled "front ends" for micro and millimeter wave communications satellites. A number of mechanical machines are currently in development for attainments of 1-3 years of unattended life and solid-state machines with no moving parts and indefinite life may also be possible. These refrigerators have inherently large demands for power, which should not be a problem due to the availability of ample power made possible by inexpensive space transportation, orbital assembly, and orbital servicing as discussed in 3.1.2.

The potential of many of these advanced technology areas will only be fully realized if space assembly and servicing is practiced routinely. Additionally, the role of man may well be fundamental in many advanced applications of space technology, whether as on-line operator or in supporting roles.

The second category of technology items identified pertains to those recognized as having great potential but not exploited in this study for synthesis of systems concepts due to insufficient knowledge of the phenomenology. These items are shown in the lower half of Table 3-1. An example of such technology is the concept of radiation engineering at frequencies in the so-called "infrared-microwave gap" extending from about 50 μm to 1000 μm. Lasers operating in this region have been recently developed, and indeed a waveguide laser is in operation at The Aerospace Corporation. In combination with heterodyne detectors, also for ground-space communication, or for space-ground sensing applications if tuned to a narrow spectral window in the atmospheric attenuation curve. Though the likelihood of finding such a low-attenuation window is not large, the complete region has not been explored with sufficiently fine spectral resolution to warrant a completely negative conclusion at this time. Since the radiation wavelength is longer than the size of particles in most clouds, it would have the property of cloud penetration with little scatter, rendering feasible nearly all-weather sensing and communications systems much smaller than current satellites using microwaves.

Other areas are also listed in Table 3-1, including the production of difference frequencies in space plasma. It is likely that many system concepts of great power might be feasible if proper attention were given to such technology areas.

3.2 TECHNOLOGY PROJECTIONS

This portion of this section presents quantitative technological forecasts in the areas of large structures or arrays in space as applied to antennas, optics, and computers. Detailed forecasts in high power/energy; lasers; CCDs; and cryogenic refrigerators have not been made, however, the growth expected should parallel the developments illustrated. Where necessary for attainment of a desirable and otherwise feasible system capability in Section 4, the assumption was made that the technology could be made to grow to support such capability by proper funding and priority. The specific requirements on technological growth are summarized in Section 9.3, as well as in Volume IV. The technology projections discussed in this section include current capabilities, those expected to be available in the 1980-1990 (near-term) period utilizing straightforward extensions of current techniques, and those which could be available in the 1990-2000 time period utilizing new techniques and great extrapolation.

3.2.1 Large RF or Microwave Antennas

The first technique discussed is that of single-dish antennas, which is illustrated in the top row of Figure 3-1, in which the current state of the art

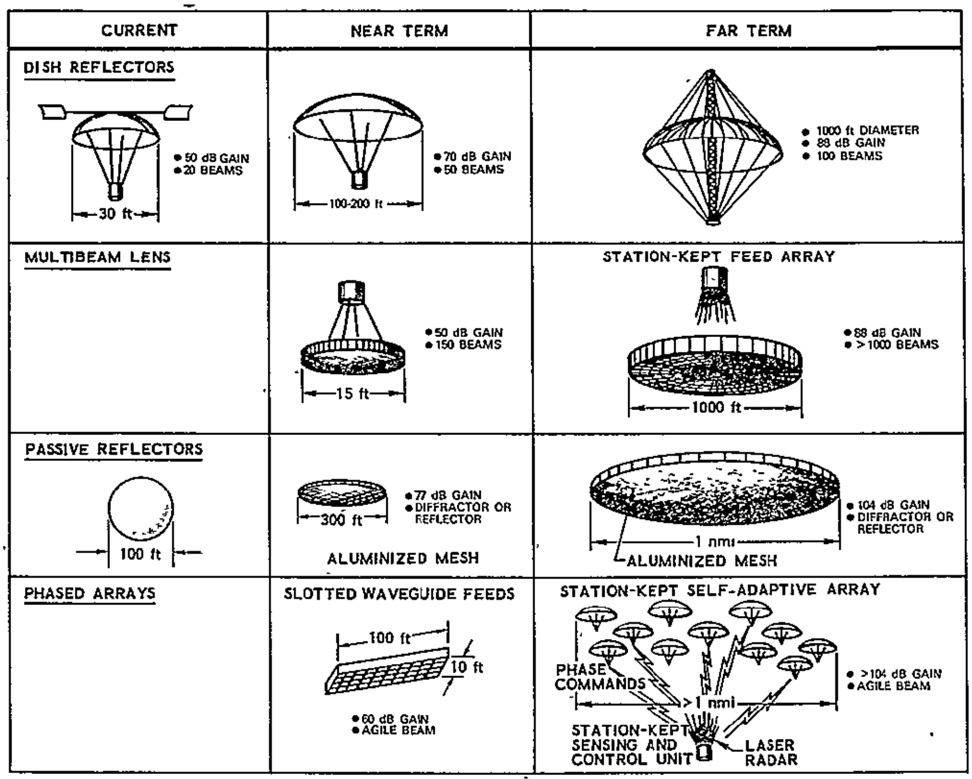


Figure 3-1. Large RF/Microwave/ Communication Antennas

is 30 feet as represented by the ATS-F. This capability can readily be increased in the near term to single-dish erectable or assembled reflectors with size in the order of a few hundred feet diameter. In the far term, single-dish erectable or space-assembled antennas in the 1000-3000 foot diameter range have been proposed and will undoubtedly be feasible. Extrapolation to such sizes involves segmented reflector or lens panels, each adjustable relative to a primary structure to maintain phase-front coherence. The tolerance required at S-band (0.1 m wavelength) is about 0.5 cm in 500 m or $\sim 1/10^5$, a sizable undertaking for such structures.

The second technique is that of multibeam lens antennas, illustrated in the second row of Figure 3-1, which are well adapted for generating a number of beams simultaneously each with the same gain as given by the main aperture. One mechanization is that of multiple feeds, each illuminating a bootlace or dielectric lens. There are no lens antennas currently operating in space, though the ATS-F generates 16 separate beams with a parabolic reflector. Since currently designs exist for five-foot lens antennas with 60 beams, the state-of-the-art capability for the next five or ten years will be lens antennas of the order of 15-feet diameter and 100-200 beams. This technology can be extrapolated to sizes in the order of 1000-feet diameter or more, even though the lenses become extremely heavy and favor the application of dielectric or composite wave delay structures. In such sizes, the feed horn arrays could be stationkept rather than physically trussed to save weight. The multibeam antennas are ideal for applications where large apertures (in terms of wavelength) are needed and where large coverage (in terms of beamwidth) are needed simultaneously. A complete separation of the beam generation and beam forming functions is possible, allowing the placement of the respective components far away, even on the ground, readily leading to the application illustrated in the third line of Figure 3-1, which is that of passive reflectors. Such reflectors can be mechanized by a stretched mesh or by thin-film membranes with metallized conductors or surface coatings. Reflectors or diffractors are feasible depending on the conductor spacing, forming either simple RF mirrors which are frequency independent, or gratings whose direction of beam transmission or reflection depend on the frequency. In the latter case, beam scanning could be accomplished by frequency modulation, an inertialess parameter.

Currently, the 100-ft ECHO balloon represents the largest reflector in orbit. Meshes or films stretched inside of a truss several hundred feet in diameter are possible in the near term and several thousand feet in diameter in the far term. These antennas will allow the complicated, heavy, and expensive components of some transmission concepts to be placed on the ground.

Phased arrays are illustrated in the last line of Figure 3-1, built with their receiving or transmitting elements lumped or distributed throughout the extent of a single structure, allowing the formation of agile beams or transmission of large amounts of power. Though currently there are no phased arrays operating in space, in the near term arrays at least 10 x 100 ft are considered feasible, and designs for 3000-ft diameter have been proposed. Designs of such sizes would have to be continuously adjustable in smaller segments in order to maintain the required surface accuracy of about 0.05 wavelengths.

In the far term, instead of constructing one very large structure, a technique has been conceived at The Aerospace Corporation under this contract. In this technique, a number of small sub-arrays or sub-elements of the antenna, with total area about equal to that of a single structure, but consisting of smaller dishes, individual dipoles, or collections of dipoles, would be coarsely stationkept with respect to each other and to one or more central sensing and control units, also stationkept in the vicinity. Small laser radars aboard the control units would measure the position of each element to an accuracy of a small fraction of the RF wavelength being used, and then adaptively command the phase of the feed in each sub-array to cause in-phase reception or in-phase generation of energy by the elements of the array. The laser command units would also measure angle and attitude of the elements and issue commands for controlled stationkeeping. Indeed, with sufficiently precise measurement and control, the accuracy of stationkeeping may be such as to preclude the need for phase control. Using the elements of such a technique, space antenna arrays measuring many miles across should be as feasible as much smaller ones incorporating only a few elements.

The sensing unit could alternatively sense phase information directly, be in the near vicinity or far away, or be single or multiple for triangulation. Very dense as well as highly thinned antenna arrays should be possible, consisting of identical modular elements, and comprising antenna arrays of arbitrary size in space. In basic terms, physical webs would be replaced with information webs, which should result in lighter weight antennas and contribute to basic feasibility of construction in very large sizes. Antennas constructed in such an "adaptive array" fashion are utilized heavily in syntehsis of the initiatives of Section 4.

3.2.2 Large Optical Apertures

Figure 3-2 presents technology projections for optical collectors in an analogous treatment to that in Figure 2-2. The current state of the art of diffraction-limited single optics is about five feet in diameter, as implied by the designs for NASA's Large Telescope Program. In the near term, technology could probably support diameters of several tens of feet in segmented mirrors with active figure control. The active figure control, implied by the arrows in the first line of Figure 3-2, would be accomplished by distorting the surface of each segment of the mirror by applying pressure to the back plate or by moving the mirror itself, using actuators controlled in an adaptive manner and responsive to a sensor which senses the performance of the segment or of the entire optical system. Such techniques are now being discussed in the literature for cancellation of the effects of atmospheric scintillation in ground-based systems. Extrapolation of such techniques to space mirrors in the far term may permit diameters in the order of 30 to 100 feet, which would be near-diffraction limited at 0.5 μm and have a resolution of 10^{-8} radians, corresponding to a resolution of five feet on the ground from synchronous altitude -- an enormous increase over the current capability.

The above mirrors will undoubtedly be heavy and it may not be possible to extrapolate them to very much larger diameters. A second technology has been forecast consisting of thin-film mirrors or collectors. In the second row of Figure 3-2 we see that by stretching a thin aluminized mylar film or equivalent inside an erectable lightweight stretching frame, a very lightweight mirror of large size can be made. Single films would

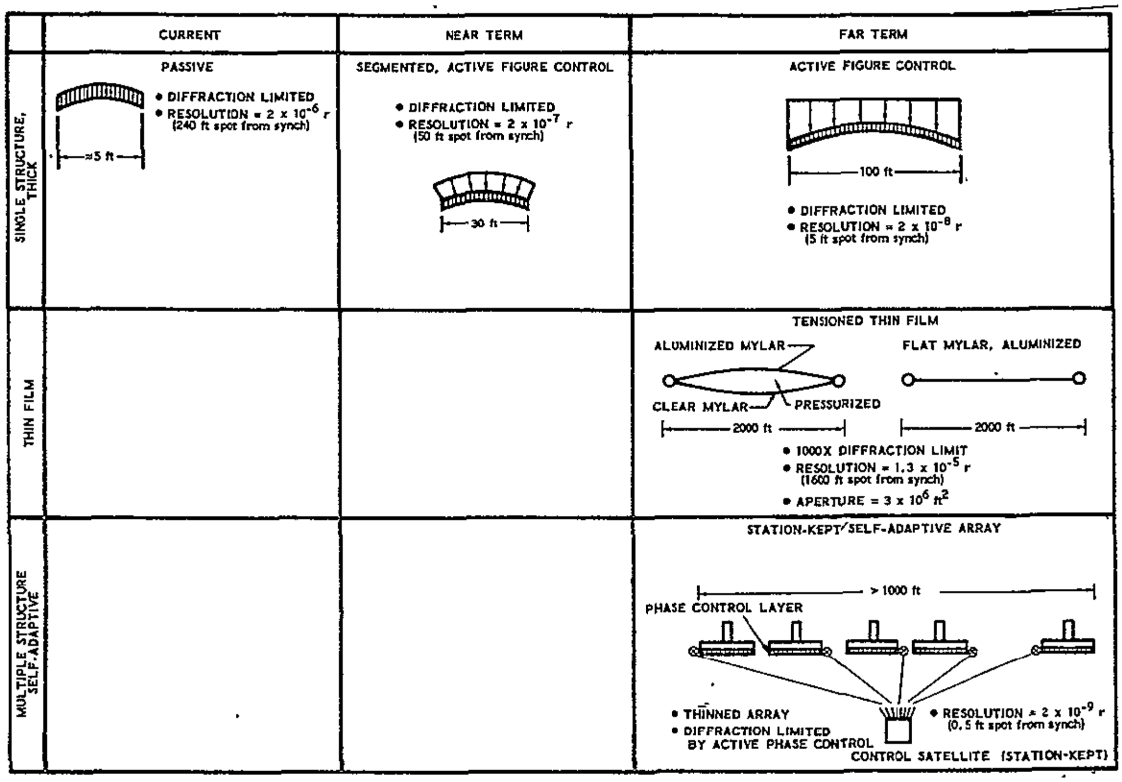


Figure 3-2. Large Optics/Mirrors

form plane mirrors, and two films attached at the outer edges with gas between them will take on a doubly-spherical figure, resulting in a focusing mirror if one film is clear and the other one is aluminized. Designs for flat mylar mirrors have existed for a number of years, but none have yet been built in space. It is unlikely that, due to the inhomogeneity of the film in manufacture, diffraction-limited performance can be attained in sizes in the order of thousands of feet. On the other hand, for applications where optical quality is less important than aperture, these mirrors have the potential for extremely small weight-per-unit collecting area and for comprising very large apertures.

In the last row of the last column of Figure 3-2 is illustrated a far-term concept for construction of very large apertures of high optical quality without requiring that tolerances of a fraction of the optical wavelength be held over the dimensions of the array. This technique is more difficult than its analog, the RF adaptive array in which the phase front is corrected electronically, due to the much smaller wavelength and the relatively less well developed technology of discrete phase control. It can be considered to be an extension of the adaptive segmented optics of the upper right corner of Figure 3-2. Each of the units in the array would be an independent satellite, coarsely stationkept. A small control sub-satellite measures the range, position, and attitude of each of the sub-satellites with a small laser which information is used for stationkeeping. Each satellite mirror could be coated with a material whose index of refraction can be controlled in some manner, say, by the application of electric fields across the material -- such that the phase of light reflection off that mirror can be changed by command from the control satellite. By sensing some of the reflected energy from each of those mirrors at the control satellite, phase changes could be commanded to give constructive interference at the focal point regardless of the physical position of the reflectors themselves. Although the technology needs considerable development compared to its RF analog and particularly the phase control material, there appears to be no fundamental reason why it could not be made to work. Alternatively, the primary mirrors could be passive and the corrections could be made at an intermediate distance between the mirrors and the focal plane, with the correcting mirrors also actuated or distorted for phase control (or layer controlled). Such control mirrors would be expected to be much smaller and lighter than the primary mirrors. With such techniques, it is possible that thinned optical arrays at least 1000 feet in diameter should be obtainable. Furthermore, the inherent capability of rapidly correcting a distorted phase front could allow for some reduction in the effects of atmoshperic scintillation, resulting in systems which might have a resolution of less than a few feet on the ground from synchronous altitude.

Figure 3-3 illustrates in a little more detail one concept of such a self-adaptive array technique. In the microwave region the technique

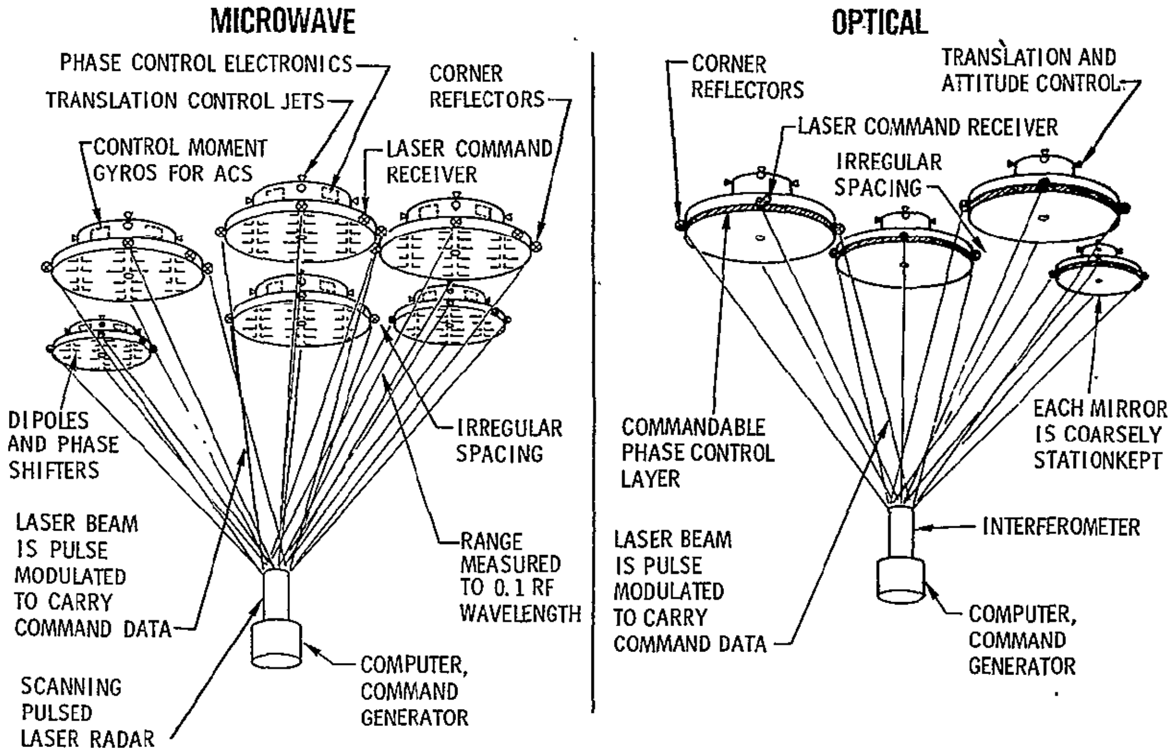


Figure 3-3. Self-Adaptive Array Techniques

for controlling the phase of the transmission or receptions is well understood. It is done under the control of a master station, one version of which measures the relative position of the elements to a fraction of the RF wavelength and commands phase shifters in each element. In the optical region, a fringe-counting interferometer could be used for position determination to a fraction of an optical wavelength, and the phase control could be accomplished by commanding the refractive index of special coatings over the mirrors (by electric field excitation for instance) or by deforming or translating the front surface of the mirror, thus changing the phase of reflection in response to an image quality measurement and resulting in constructive interference addition of the components from each mirror at the stationkept focal plane. The laser radar can be used to measure the position and attitude of each unit very precisely using multiple corner reflectors on each element, thus serving as a remote attitude reference unit, using the laser itself as a command link to command the attitude and translational position required to each unit. This would result in less expensive and modular stationkept elements. Alternatively, the resultant phase of each element or of the combined array could be measured remotely, even on the ground, and used for sequential or parallel phase command generation.

Adaptive phase control techniques are clearly the direction of aperture development for the future and were therefore applied in many of the initiative concepts for forming extremely large antenna and optical arrays in space. It is probable that the adaptive arrays would at the very least have the advantage of lower weight than equivalent monolithic systems, and that they might actually represent the only feasible technique for devising extremely large apertures.

A brief technology projection was made in the information processing area. As illustrated in Figure 3-4, the current capability in spaceborne computers is represented by the Space Shuttle computer.

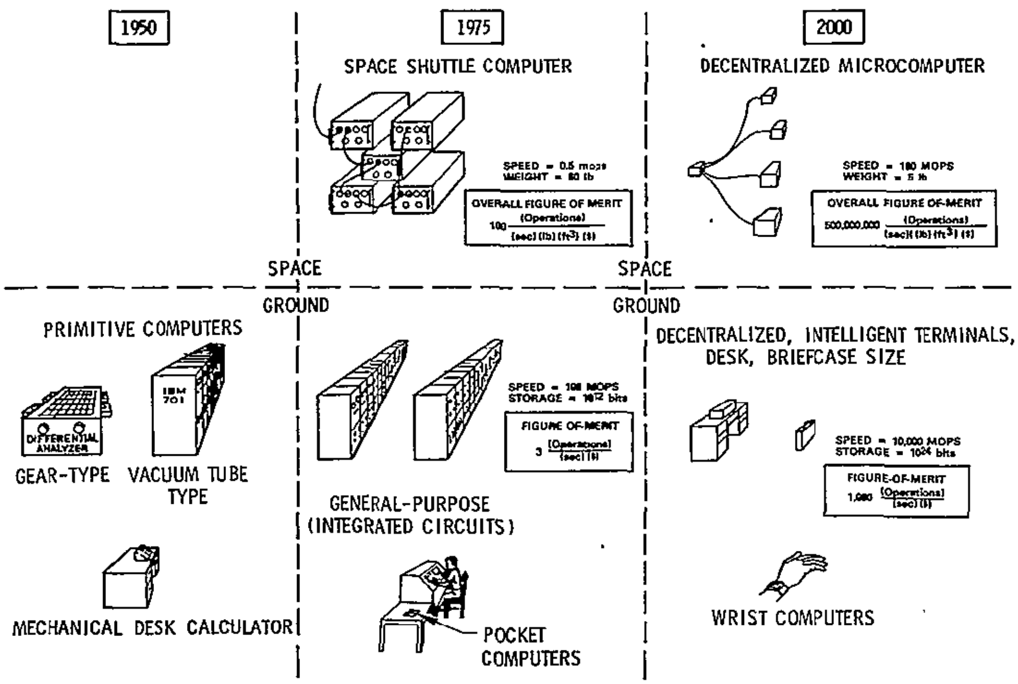


Figure 3-4. Technology Trends: Information Processing

The control processor has a speed of about 500,000 operations per second, and a weight of about 60 lb. The overall figure of merit of such a computer is about 100 operations per second per pound of weight per cubic foot of volume per dollar cost. In contrast, the space computer of the year 2000 will be constructed wholly of large-scale integrated circuitry, will be decentralized to allow preprocessing at the origination site of the data, will weigh about five pounds, have a speed of more than 100 million operations per second, and a comparative figure of merit of about 500 million, an increase of five million over the current space computer generation.

This enormous increase in capability will be reflected in near-real-time processing of data in space at the source, allowing essentially any function in information gathering, processing, and dissemination to be carried out reliably at low cost and weight.

3.3 NEAR-TERM GROWTH OF CURRENT PROGRAMS

The advanced technology discussed above will enable new and highly capable system concepts to be realized in the next 25 years. Such concepts will in general grow in capability in steps starting from current programs.

This study emphasizes applications of this new technology to concepts which offer dramatic steps in improved performance, or entirely new capabilities (as contrasted to the near-term growth of current systems usually described in five or ten year projections of current missions), though some concepts in this study are of the latter type.

The starting point of most concepts described in this study begins where such near-term growth leaves off. The near-term improvements are illustrated in Figure 3-5, and are shown to offer essentially quantitative performance improvements: somewhat better resolution, more channels, more sensitivity, etc. A few cases of new capability will be introduced in the near term, including the SEASAT Orbital Radar and the Tracking and Data Relay Satellite, however, by standards of what

FUNCTION	TYPICAL CURRENT	NEAR-TERM GROWTH
1. Communications	INTELSAT IV, ANIK	INTELSAT V
• Trunking	- operational - 10^4 circuits	- multiple beams - frequency reuse - more capacity - FDMA/TDMA
• Small User	ATS-F - experimental - van terminals - TDMA	MARISAT, AEROSAT - VHF/UHF - maritime, aircraft service
• Data Relay	--	TDRS - experimental systems
2. Surveillance		
• Land	LANDSAT (ERTS) - multispectral imaging	- improved resolution - more spectral bands - more storage/TDRS readout
• Ocean	--	SEASAT - ocean physics, sea conditions

Figure 3-5. Near-Term Growth of Current Programs (Civilian)

FUNCTION	TYPICAL CURRENT	NEAR-TERM GROWTH
3. Meteorology	NOAA, NIMBUS, SMS	- multispectral - improved resolution - improved sensitivity - lower cost
4. Navigation	none	Military will provide.
5. Earth Physics	ANNA, GEOS, PAGEOS, SECOR	- SEASAT (sea conditions) - LAGEOS (laser geodetic sat) - GRAVSAT (gravity gradi-ometer) - MAGNETIC MONITOR (mag field)

Figure 3-6. Near-Term Growth of Current Programs (Civilian)

could be done in the next 25 years with the advances in technology postulated in this section, even such capabilities will be seen to be very modest.

The purpose of this reasoning is not to discourage, denigrate, or oversimplify the near-term growth of current programs, which in itself is difficult enough, but rather to contrast the current study.

The military programs have been omitted due to security classification reasons.

4. INITIATIVES (SPACE SYSTEM CONCEPTS)

The application of the advanced technology thoughts and projections described in Section 3, together with the general principles and perspectives of space applications and operations addressed in Section 2 resulted in the collection and innovation of a number of space system concepts (initiatives). These are functionally described in this section, and presented in catalog format in Volume III.

By "initiative" is meant the description of a space system designed to perform a function not being performed today, and represents an opportunity for the acquisition of such a function. Each initiative is treated independently of all the others, though in many cases the functions performed by several initiatives could clearly be combined into a smaller number of multi-function satellites. Whether such is desirable or not has not been addressed in this study.

Though a large portion of the initiatives were originated by the study team and are the result of innovative conceptualizing, some are restatements of ideas put forth in the past, some are an outgrowth of discussions with key people in government, industry, and science, and a few were suggested explicitly in such discussions.

None of the initiatives are advocated per se by the study team, The Aerospace Corporation, or NASA, though some of the general application areas illustrated probably could benefit the National Space Program. Each initiative could be mechanized in somewhat different form than that shown in this report, with somewhat different numbers and attributes. No claim to uniqueness of design is made within the broad applications of the prinicples espoused in Sections 2 and 3. It should be emphasized that the initiatives are intended to illustrate the varied application of those broad principles, and not to circumscribe them, and thus the specific initiatives must be viewed as examples from a far larger set yet to be defined. The number of initiatives in this report was bounded by limitations in resources, time, and priorities within the study tasks. Clearly a further concerted effort on the part of the study team or other appropriate individuals or teams would result in a far larger list.

The concepts were generated without imposing limitations due to current technology, current or projected budgets, policies, treaties, etc., so that they would be representative of what could be done given the intent. Furthermore, no calculation of cost-benefit was attempted, and all concepts which could be quantitatively defined and appeared to have some utility were included regardless of their merit or lack of merit compared to terrestrial approaches or to other space approaches. In particular, some of the concepts could materially impact the fabric of society if implemented, but the societal impact was not specifically identified or evaluated in this study.

Some of the initiative concepts may be viewed with favor, and if so, we recommend that in addition to further technical definition, the crucial questions of benefits vs. risks vs. costs must be addressed by those who may wish to advocate them.

The initiatives represent concepts of different technological difficulty and risk, varying from modest satellites which are straightforward extensions of current techniques and which could be orbited with low risk in the early 1980's to those which require giant leaps in technology, require major national commitments, and might even pose some hazards in their application. In order to clearly identify the risk associated with the concepts they have been categorized in accordance with four categories as defined in Table 4-1. This table is used to separate the straightforward systems of the early 1980's (Category I and maybe III) from the riskier extrapolations of the early 1990's (Category II) and particularly from the "mind-benders" of the year 2000 era (Category IV).

The initiatives are illustrated with a standard format shown in Figure 4-1. Only initiative concepts were included for which preliminary characteristics and performance could be ascertained. Each initiative has.

Table 4-1. Categorization of Initiatives - Degree of Risk

CATEGORY I - (LOW)

- READILY EXTRAPOLATED FROM CURRENT TECHNOLOGY
- RELATIVELY LOW TECHNOLOGICAL RISK
- NO HAZARDS ASSOCIATED WITH OPERATION

CATEGORY II - (MEDIUM TECHNOLOGY)

- CONSIDERABLE EXTRAPOLATION OF CURRENT TECHNOLOGY
- DEMONSTRATION PROGRAMS REQUIRED AS PROOF-OF-CONCEPT
- PHENOMENOLOGY WELL UNDERSTOOD
- NO HAZARDS ASSOCIATED WITH OPERATION

CATEGORY III - (MEDIUM PHENOMENOLOGY)

- PHYSICS UNDERSTOOD, BUT PHENOMENOLOGY NUMBERS NEED VERIFICATION
- TECHNOLOGY CAN PROBABLY BE EXTRAPOLATED FROM CURRENT STATUS
- DEMONSTRATION PROGRAMS REQUIRED AS PROOF-OF-CONCEPT
- NO HAZARDS ASSOCIATED WITH.OPERATION

CATEGORY IV - (HIGH)

- GREAT ADVANCES IN TECHNOLOGY REQUIRED
- FAR FUTURE APPLICATION - CONCEPTUAL ONLY
- CONSIDERABLE HAZARDS POSSIBLY ASSOCIATED WITH OPERATION

- PURPOSE
- RATIONALE
- CONCEPT DESCRIPTION
- CHARACTERISTICS
  - WEIGHT
  - SIZE
  - RAW POWER
  - ORBIT
  - CONSTELLATION SIZE
  - RISK CATEGORY
  - TIME FRAME
  - IOC COST
- PERFORMANCE
- BUILDING BLOCK REQUIREMENTS
  - TRANSPORTATION
  - ON-ORBIT OPERATIONS
  - SUBSYSTEMS
  - TECHNOLOGY
  - OTHER

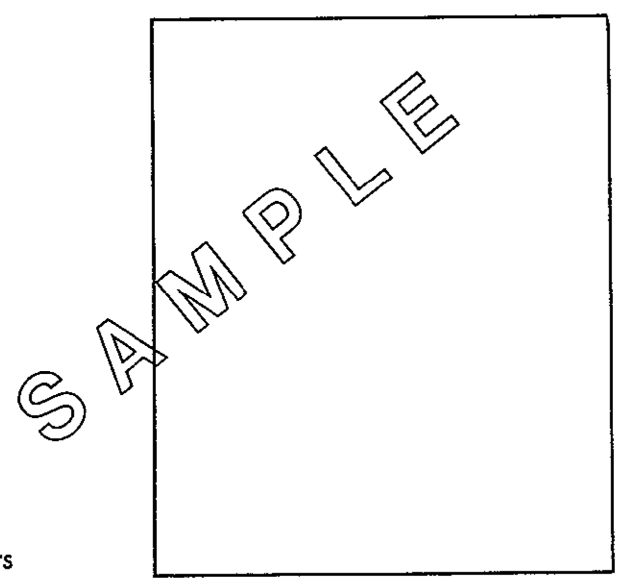


Figure 4-1. Sample

had sufficient preliminary thought to grossly define the system concept, to estimate the satellite gross weights and sizes; and to define the major performance parameters of key space and ground elements. A pictorial is presented of the function to be performed.

A brief statement is made of the purpose of the initiative and of the reasons why such an initiative might be useful. The concept is very briefly described. The characteristics of the satellite are summarized in terms of gross weight, size, and raw (prime) power on orbit. The orbit characteristics are given. The number of satellites required to form an active constellation resulting in the calculated performance is given. The degree of technological or other risk is estimated. The time frame during which the described conception of each initiative could be orbited is estimated, as well as the cost of the space segment to the first operational capability including R&D, investment in the first complete constellation, and the required booster costs. The performance is described in terms of those numbers most relevant to the utility.

For each initiative concept, the building block requirements including booster type, orbital transfer vehicle type, and orbital support facility type are stated and any special requirements on the subsystems or technology identified. If there are no special requirements beyond today's technology, those sections are left blank.

The initiatives are presented organized into civilian and military initiatives.

4.1 CIVILIAN INITIATIVES

The civilian initiatives are organized as follows:

4.1.1 Personal Applications

Most personal applications of space involve some form of communications. The past and current practice in space communications had tended to place emphasis on relatively small, inexpensive satellites which in turn could only communicate with a few large, fixed, and expensive earth terminals. Clearly if personal, portable communications using space is to be feasible, the past trend must be reversed, and the satellites made large, complex, and relatively expensive so as to make possible communications with wearable terminals of very small size, power, and cost. The satellites could be in synchronous orbit so that only one or at most a few would be required, but would in turn allow communications to, from, and between millions of user terminals. Not only would this provide a service not available otherwise, but the total system cost, including the satellite and all terminals would be minimized. Such capability could allow millions of ordinary citizens to personally relate to space and obtain a benefit from space in the course of their everyday lives, which could produce a high degree of popular support for space.

The initiatives presented in this "personal" category include:

1. Personal Communications Wrist Set
2. Voting/Polling Wrist Set
3. Personal Navigation Wrist Set

Applications of this type depend on large space antennas in order to establish the large capture area required to make up for lack of antenna area and transmitted power in the personal user terminal. The use of microwave frequencies also appears warranted to ensure adequate radiation efficiency of the physically small user antenna when transmitting. The large satellite antenna is thus expected to be highly directional, with a beam "footprint" much smaller than the U.S.A. land mass, requiring multiple beams for large area coverage. The typical configuration developed in the initiatives for this application is therefore a multi-feed cluster of horns illuminating a microwave lens, each horn giving rise to one beam with gain determined by the full diameter of the lens. In principle, one switched transmitter and receiver could be utilized in conjunction with each horn.

The ability to communicate to and from a very large number of users demands a low-cost user terminal. The small size and weight of a personal set demands in turn very low transmitter and idle power in order to allow the use of tiny batteries and yet result in a reasonable life on a battery charge, say 24 hours of continuous use. Current advances in microelectronics such as found in digital watches and pocket calculators make a wrist radio of the "Dick Tracy" type eminently feasible. The electronics required are no more complex than now produced on single "chips" of integrated circuits, and since the volume production cost of a chip tends to be fairly insensitive to the complexity of the actual circuit on the chip, the cost of the wrist radio should not exceed the cost of today's chip-equipped electronics. Pocket calculators now cost around $10.00. It is probable that within a few years digital watches will, too. Walkie-talkies with discrete components now retail for under $5.00. It is highly probable that the wrist radio terminal can be mass-produced for a retail "drug store" price of less than $10.00, ten years from now.

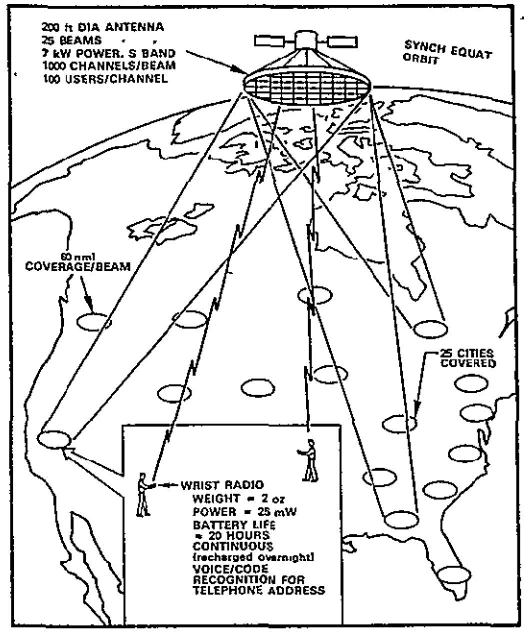
Extensive use of microelectronics in the satellite will be required to allow the demodulation, processing, switching, and remodulation of signals in space, and will be achieved using one or more schemes of multiple access, including frequency division, time division, code division, or combinations thereof. The satellite is therefore seen as a telephone switching center in the sky. With proper development, a single such satellite could service millions of people who could then talk to each other directly wherever they were on land or sea, or enter the telephone networks through the microphone on their "wrist radio" for total communication flexibility. The initiative concept is illustrated in Figure 4-2.

Additional functions which the same or similar "wrist-radio" sets in conjunction with similar satellites could provide would be to radiate

- **PURPOSE**
  To allow citizens to communicate through exchanges by voice, from anywhere.
- **RATIONALE**
  Mobile telephones are desirable, but should be wrist worn. Uses include emergency, recreation, business, rescue, etc.
- **CONCEPT DESCRIPTION**
  Multichannel switching satellite and wrist transmitter-receivers connect people anywhere to each other directly or to telephone networks. Analog or vocoded voice used.
- **CHARACTERISTICS**

• WEIGHT	16,000 lb
• SIZE	200 ft dia antenna
• RAW POWER	21 kW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1990
• IOC COST (SPACE ONLY)	300M

- **PERFORMANCE**
  25,000 simultaneous voice channels, each shared by up to 100 users: 2.5 million people communicate by normal voice.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and large/tandem tug or SEPS
• ON-ORBIT OPERATIONS	Automated or manual servicing unit; assembly on orbit
• SUBSYSTEMS	Attitude control; antenna; processor; repeater
• TECHNOLOGY	Large multibeam antenna; multi-channel repeater: LSI processor, multiple-access techniques
• OTHER	Wrist transceiver, LSI technology

Figure 4-2. Personal Communications Wrist Radio (CC-9)

emergency signals for worldwide search and rescue of crash victims, lost hikers, etc.; means by which people who felt they were in danger in the cities or anywhere could instantly call the police for help, reducing a large element of fear in urban life; means by which a large fraction of all registered voters could be instantly polled by their representatives on issues of importance or great controversy; means by which people could vote rapidly, conveniently, and accurately in elections -- maximizing the "vote turnout," and others. An initiative to provide such a service has been prepared and is illustrated in Figure 4-3.

Other applications of similar "wearable terminals" include the monitoring of vital body functions such as heartbeat and respiration in confined ill or post-operative but ambulatory patients, and the automatic transmission of emergency alert messages to medical monitoring facilities for instant response and care.

- **PURPOSE**
  To provide direct access to entire population for voting or polling purposes.
- **RATIONALE**
  Voting and polling are time-consuming processes, subject to many errors due to small sample size.
- **CONCEPT DESCRIPTION**
  Multi-channel satellite queries wrist radios, and relays responses to Washington from individual voters. Unique voter pseudo-random codes.
- **CHARACTERISTICS**

• WEIGHT	13,000 lb
• SIZE	150-ft dia antenna
• RAW POWER	90 kW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	1 (Low)
• TIME FRAME	1990
• IOC COST (Space only)	300 M

- **PERFORMANCE**
  100,000,000 people polled/vote in one hour. Any 10-bit message relayed automatically upon query by satellite.
- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and tandem tug
• ON-ORBIT OPERATIONS	Automated or manual servicing unit; assembly on orbit
• SUBSYSTEMS	Attitude control; antenna; processor
• TECHNOLOGY	Large multibeam antenna; multi-channel transponder; LSI processor; multiple-access techniques
• OTHER	LSI wrist transceiver

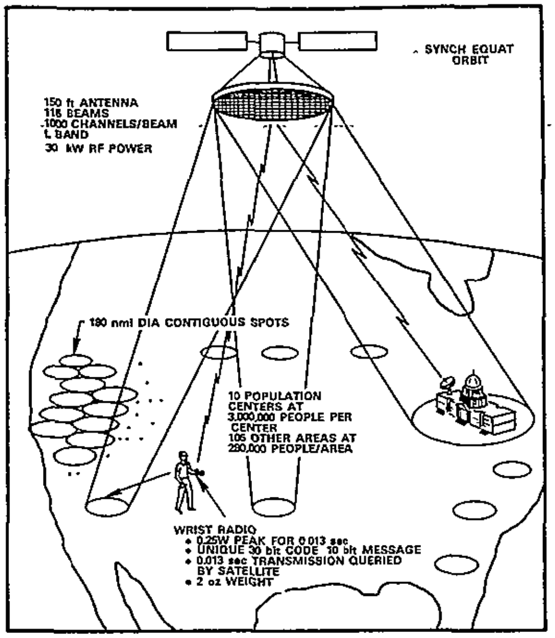


Figure 4-3. Voting/Polling Wrist Set (CC-7)

The first initiative (Figure 4-2) sets up 25,000 simultaneous voice channels through a single satellite, which can service upwards of 2.5 million people with one satellite, depending on the number of people sharing a channel. The example shows 25 urban areas covered by a 25-beam satellite, each beacon covering a 40 nmi area. There is no reason why 250 areas, or the entire country could not be covered, it requiring only more beams, more receivers, and transmitters. The second initiative (Figure 4-3) allows push-botton digital message or vote transmission using wearer-unique pseudo-random codes for identification, and allows 100 million people to be polled or to vote in one hour, making possible a more participatory democracy. Note that the satellites required are large by today's standards, with 200-ft diameter antenna and weighing close to 20,000 lb, yet could be orbited by a single Shuttle and a large or tandem Tug or Solar-electric stage in the 1990 time period if not sooner.

The extensive electronics and control devices on board will probably require on-orbit servicing in order to extend the satellite life beyond a few years, and servicing at three-year intervals has been assumed, extending indefinitely the operational life and maximizing the return on the investment. The estimated cost of about $350 million includes all necessary development and test, the purchase of the operational satellite, and the transportation required to place it in orbit. This type of system is low risk, since it is only a larger version of communications satellites already in orbit or programmed to fly in the early 1980's, and all the technology is well understood.

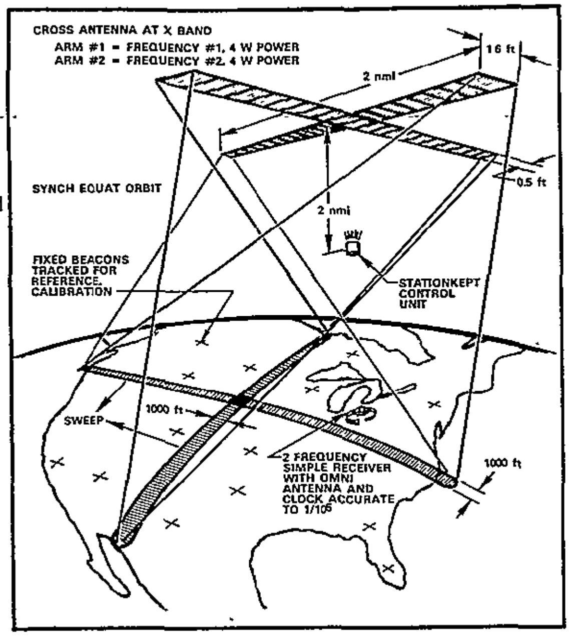
The satellite communications subsystem consists of 25 RF sections, one for each beam, with 1,000 3 kHz bandwidth IF and detector sections separated by 10 kHz between subcarriers following each RF section. There are also 1,000 modulation sections feeding each of 25 transmitters, one for each beam. There is also a large corporate cross-switch to connect any receiver with any transmitter. In operation, the satellite processor recognizes the address code preceeding a message and uses that information to make the proper interconnects. The satellite also controls access to the channels by assigning a place in a queue and a channel to each user wishing access to the satellite. In this way the maximum number of people can access the satellite with minimum waiting time. Emergency messages would, of course, override the queue.

The use of much larger satellite antennas measuring in the order of one mile across could provide a personal navigation function to an unlimited number of users with "wrist radio" receivers by setting up extremely narrow sweeping radio beams from space which would cause pulses in the simple wrist receivers whenever the beam swept over the wearer. Counting the timing of such pulses using a simple oscillator "clock", the wrist radio would indicate the wearer's location, heading, and even speed on a small digital light display on the face of the sets not unlike that of today's digital watches or pocket calculators. Such a concept, illustrated in Figure 4-4, could provide an unlimited number of people with an all-weather

- **PURPOSE**
  To provide accurate relative position location with very inexpensive user equipment.
- **RATIONALE**
  Navigation system costs are dominated by user equipment costs.
- **CONCEPT DESCRIPTION**
  Narrow beams are swept over the U. S. by large phased arrays in space. Very simple receivers measure time elapsed between pulses received and display distances (N-S, E-W) to fixed point.
- **CHARACTERISTICS**

WEIGHT	3000 lb
SIZE	2 nmi cross
RAW POWER	2 kW
ORBIT	Sync. Equat.
CONSTELLATION SIZE	1
RISK CATEGORY	II (Medium)
TIME FRAME	1990
IOC COST (SPACE ONLY)	100 M

- **PERFORMANCE**
  - User position located to 300 ft every 10 sec relative to a fixed location < 100 nmi away.
  - User receiver can cost less than $10 in mass production.



- **BUILDING BLOCK REQUIREMENTS**

TRANSPORTATION	Shuttle and Tug
ON-ORBIT OPERATIONS	Manned or automated assembly and servicing units
SUBSYSTEMS	Antenna with independently stationkept subunits.
TECHNOLOGY	Ion thruster, adaptive RF phase control, laser master measuring unit
OTHER	LSI receivers

Figure 4-4. Personal Navigation Wrist Set (CS-7)

capability of navigation. In use, the coordinates of a desired goal (such as one's house, office, intended building, home port, or base camp) would be entered into the receiver memory by push button. Then the display would indicate the number of feet (or miles) the wearer is located north (or south) and east (or west) of the goal. The wearer could simply proceed until the display read 0, and be at the goal. Alternatively, coordinates of all locations could be printed on navigation maps calibrated for this navigation satellite. The concept illustrated allows relative navigation to an accuracy better than 300 ft in areas within 50-100 nmi from a reference point or goal. By the use of calibrated beacons in many areas, this accuracy can probably be extended to the entire country.

The navigation set is a simple two frequency wide-open receiver, with a simple quartz crystal clock for timing. All components are very similar to a digital watch, and are again expected to sell for less than $10 ten years from now.

The large antenna in space is used for its ability to generate extremely narrow beams, rather than for its aperture. In fact, the aperture resulting from the antenna dimensions of two-miles long by about one-foot wide per arm (needed for the footprint of 1,000 ft by 2,000 nmi) results in a transmitted power requirement of only 4 watts per arm. The antenna would be constructed of a large number of stationkept subsatellites, position and phase-controlled by a stationkept measurement and control satellite to act as a coherent linear crossed array. Alternatively, the antenna arms could be supported by a monolithic structure holding the required flatness across the array.

This satellite concept is placed into Risk Category II due to the unproven status of the stationkept antenna array or the difficulty in maintaining surface flatness of about 1/4 in. across the two-mile long array.

The estimated weight is about 3,000 lb, thus one of the anticipated problems will be transporting the volume of payload required. In this case, the antenna subsatellites could be 1 x 10 ft, stacked like cordwood in the shuttle bay, and boosted as a unit by a Tug carried on a separate shuttle flight. Since 2,400 subsatellites of 1 x 10 ft would be required, proper packaging into the shuttle becomes important. Deployment, initialization, and servicing would be required, either automated or manual.

A near-term and low risk navigation function could be supplied with less accuracy for uses by coastal pleasure vessels as well as other boats. For such an application, an accuracy of relative navigation of 1/2 mile would be very useful, and could be generated with a satellite antenna only 200 ft x 1 ft for a coastline. The satellite could be lightweight and inexpensive, as illustrated in Figure 4-5.

Combining communications and navigation functions into a single "wrist radio" type of personal terminal would allow its use for voice telephone communications, rescue beacon, emergency transmitter, "panic button," voting and polling, navigation set, compass, speedometer, medical monitor, civil defense alarm, and many other functions. This type of

- **PURPOSE**

  To provide reasonably accurate relative position location in the near term with very inexpensive user equipment.

- **RATIONALE**

  Navigation system costs are dominated by user equipment costs. Wide popular need.

- **CONCEPT DESCRIPTION**

  Narrow beams are swept over the U.S. by phased arrays in space. Very simple receivers measure time elapsed between pulses received and display distances (N-S, E-W) to fixed points.

- **CHARACTERISTICS**

• WEIGHT	1,600 lb
• SIZE	160 ft cross
• RAW POWER	1 kW
• ORBIT	Sync. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	1 (Low)
• TIME FRAME	1980
• IOC COST	90 M

- **PERFORMANCE**

  -User position located to 1/2 nmi every 10 sec anywhere in USA and 200 nmi beyond coastlines.

  -User receiver can cost less than $10 in mass production.

- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and IUS
• ON-ORBIT OPERATIONS	Manned or automated assembly and servicing units
• SUBSYSTEMS	Antenna, attitude control
• TECHNOLOGY	---
• OTHER	LSI receivers

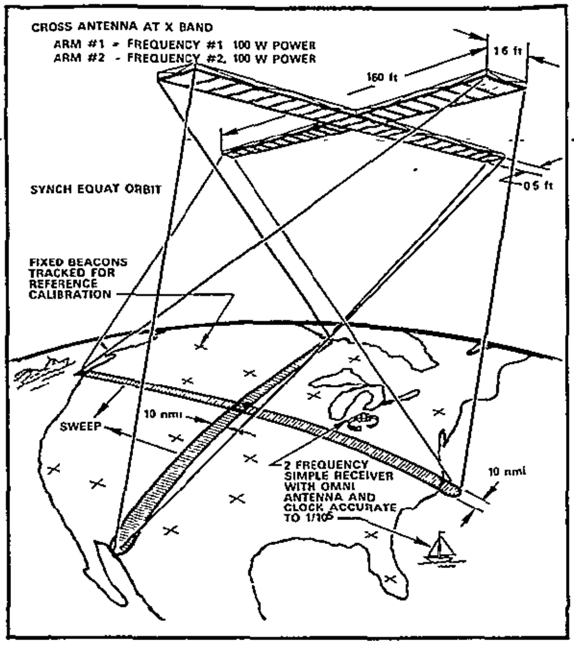


Figure 4-5. Near-term Personal Navigation Concept (CS-16)

service, whether developed by government, the private sector, or both in concert, could really allow large numbers of ordinary people to directly and personally benefit from space in the course of their everyday lives. Savings might ensue in the operations compared to use of today's techniques, and new functions provided not feasible otherwise. Furthermore, the operation of the satellite and user terminals could be a service provided by private industry, with handsome returns on the initial investments possible through use fees. Billing for use could be automatically performed in a way not unlike today's telephone system operation.

4.1.2 Civic Applications

The initiatives discussed under this category include:

1. Urban / Police Wrist Radio
2. Disaster Communications Set
3. Voting / Polling Wrist Set

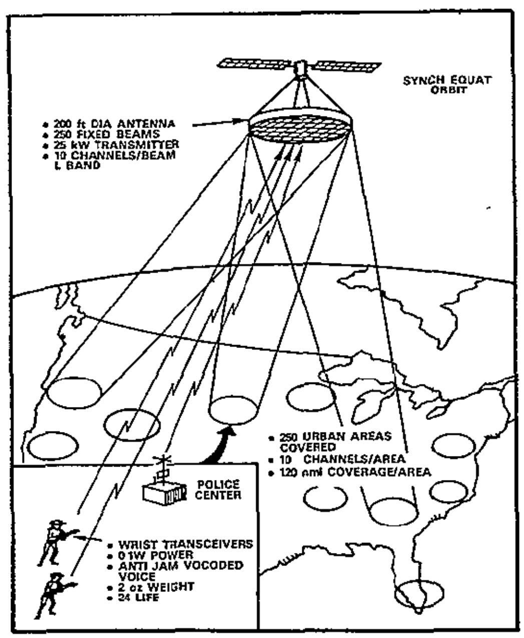
4. Burglar Alarm/Intrusion Detection
5. Vehicular Speed Limit Control
6. Energy Monitor

Satellites similar to those described for personal communications (Figure 4-2) could be used by local governments for many applications, including communications and control of police forces, in which each individual officer would have a "wrist radio" terminal similar to the personal set described above which would be appropriately coded and possess a fair degree of protection against eavesdropping and intentional jamming or interference. Officers could be constantly in touch with and responsive to their superiors regardless of location using such a system, illustrated in Figure 4-6. The illustrated system establishes 10 voice channels in each of 250 urban areas, each 120 nmi in diameter. It is also a Category II low risk concept.

- **PURPOSE**
  To give real-time, secure, anti-jam, high coverage, wide area personal communications to each policeman.
- **RATIONALE**
  Portable/personal sets needed to increase police mobility/safety. Jamming/eavesdropping will become routine.
- **CONCEPT DESCRIPTION**
  Wrist 2-way transceiver and channelized Comsat give instant 2-way communications to patrolmen. Multibeam antenna, anti-jam processing, and pseudo-random coding make jamming difficult.
- **CHARACTERISTICS**

• WEIGHT	18,000 lb
• SIZE	200-ft dia antenna
• RAW POWER	75 kW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1990
• IOC COST (Space only)	390 M

- **PERFORMANCE**
  10 Channels/city area, 250 areas simultaneously. Resists 1 kW uplink jammer and 40 kW downlink jammer two miles distant.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and large tug or SEPS
• ON-ORBIT OPERATIONS	Automated or manual servicing unit; assembly on orbit
• SUBSYSTEMS	Attitude control; antenna; processor
• TECHNOLOGY	Large multibeam antenna; multi-channel transponder; LSI processor; multi-access techniques
• OTHER	Wrist transceiver, LSI technology

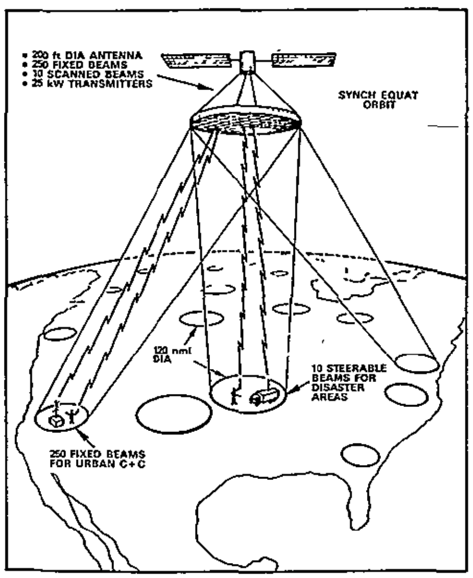
Figure 4-6. Urban/Police Wrist Radio (CC-2)

Local elections, council actions, hearings, and other functions could be facilitated by local coverage versions of the voting/polling initiative described previously in Figure 4-3. The control would rest in who received the wrist terminals, but the space system could be identical or smaller.

Emergency services such as required during and following natural or man-made large scale disasters such as tornadoes, hurricanes, floods, fires, etc., could be provided to a whole host of field workers with wrist radio terminals or to emergency relief posts by adding steerable beams to a personal communications satellite to assure coverage wherever needed or by adding the beams to a police wrist radio system. An example of such a concept is illustrated in Figure 4-7. This concept could also form the backbone of an effective civil defense or alerting system.

The ability to detect very small signals from synchronous orbit, coupled with the ability to make very small, inexpensive, and readily proliferated transmitters, enables the remote sensing of many widespread phenomena.

- **PURPOSE**
  To provide communications, command, and control to disaster area emergency personnel.
- **RATIONALE**
  Lack of communications hampers quick and effective handling of emergencies.
- **CONCEPT DESCRIPTION**
  Wrist 2-way transceivers connected to each other and to control centers through multi-channel Comsat. Anti-jam.
- **CHARACTERISTICS**
  - WEIGHT: 18,000 lb
  - SIZE: 200-ft dia antenna
  - RAW POWER: 75 kW
  - ORBIT: Synch. Equat.
  - CONSTELLATION SIZE: 1
  - RISK CATEGORY: 1 (Low)
  - TIME FRAME: 1990
  - IOC COST: 390 M
- **PERFORMANCE**
  Provides 10 disaster areas and 250 urban centers with 10 channels of voice communications each. Secure, anti-jam coded



- **BUILDING BLOCK REQUIREMENTS**
  - TRANSPORTATION: Shuttle and large tug or SEPS
  - ON-ORBIT OPERATIONS: Automated or manual servicing unit; assembly on orbit
  - SUBSYSTEMS: Attitude control; antenna; processor
  - TECHNOLOGY: Large multibeam antenna; multi-channel transponder; LSI processor; multi-access techniques
  - OTHER: None

Figure 4-7. Disaster Communications Set (CC-3)

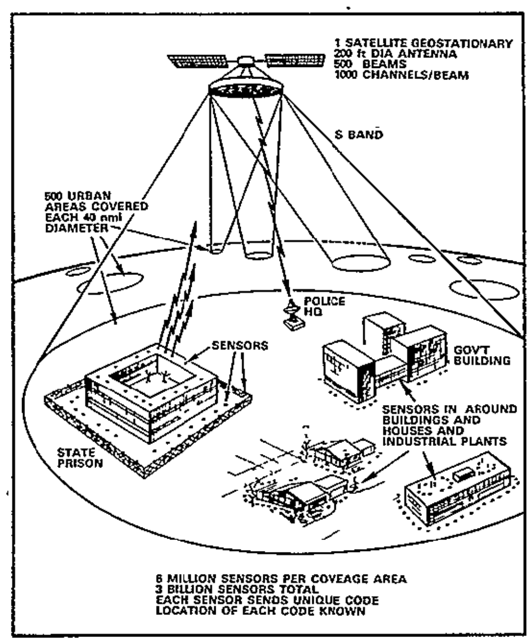
One example is an intrusion alarm or burglar alarm system where individual sensors or groups of sensors (such as door switches) or footstep sensors (such as might be emplaced in lawns or sidewalks) are coupled to tiny transmitters. A large multi-channel satellite with multibeam antenna picks up these transmissions and relays them to the closest security control center or police headquarters.

The advantage of performing such sensing functions through space is that truly enormous numbers of sensors can be monitored simultaneously. In the example illustrated in Figure 4-8, more than six million intrusions can be detected each second in each of 500 greater urban areas, or three billion intrusions each second in the U.S.A., using a single satellite. Such a capability could well replace guards around and in federal, state, and local facilities and buildings, industrial plants, and even private homes, and eliminate undetected burglaries.

- **PURPOSE**
  To detect burglars/intruders in government and industrial buildings, facilities, or homes
- **RATIONALE**
  Effective widespread burglar alarm system could reduce this enormous loss of property, productivity, and life.
- **CONCEPT DESCRIPTION**
  Very many, very tiny seismic or discrete sensors transmit when actuated. Signals picked up by single large antenna satellite for all U. S. A. and relayed to police command post nearest to area being burgled.
- **CHARACTERISTICS**

• WEIGHT	16,000 lb
• SIZE	200-ft dia antenna
• RAW POWER	1 kW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1990
• IOC COST (Space only)	350 M

- **PERFORMANCE**
  Up to six million intrusions detected every second in each of 500 urban areas, 3 billion intrusions per second total. Police alerted within 0.25 sec of entry.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and large tug or SEPS
• ON-ORBIT OPERATIONS	Automated or manual servicing, assembly in orbit
• SUBSYSTEMS	Transponder, antenna, attitude control
• TECHNOLOGY	Multiple access technique, software, antenna switching
• OTHER	Cheap sensors

Figure 4-8. Burglar Alarm/Intrusion Detection (CS-14)

This system concept is also low risk, being similar in the space segment to the personal communications initiative.

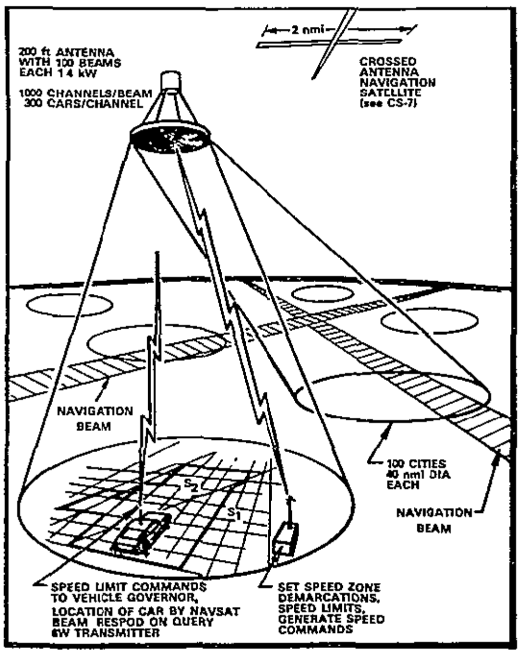
One problem in the cities is that of a high vehicle accident rate due to excessive speed on streets and freeways. So long as speed limits are voluntary, some people will exceed them. There are techniques for setting positive limits on the maximum speed at which vehicles can travel, without infringing on peoples' rights to travel where they wish at any speed below the legal limit. One way is legislate speed governors to be built into (or added to) the engines of all vehicles, the speed setting of which would be set remotely by local governing bodies normally having jurisdiction over traffic zoning and enforcement.

A satellite could then relay the speed settings desired to small receivers in each vehicle, which would limit the maximum vehicle speed appropriate for the cars' location. The location could be centrally computed, or individually determined by tiny receivers operating in conjunction with the navigation satellite described in Figure 4-4. Such a concept is illustrated in Figure 4-9.

- PURPOSE
  To establish positive vehicle speed control zones in cities by radio control of vehicle engine governors.
- RATIONALE
  Excessive speed is a major contributor to traffic accidents and injuries. With positive control, speeding is impossible.
- CONCEPT DESCRIPTION - Each vehicle has a small transceiver and a command receiver connected to a commandable speed governor. Each vehicle determines its location using crossed antenna NAVSAT. Speed commands are generated by computer on the ground.
- CHARACTERISTICS

• WEIGHT	22,000 lb
• SIZE	200-ft dia antenna
• RAW POWER	430 kW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	II (Medium)
• TIME FRAME	1990
• IOC COST (Space only)	470 M

- PERFORMANCE
  Vehicle speed controlled to ± 1 mph. Provision for one million cars in each of 100 cities (100 million total vehicles). Speed zones changed by program change.



- BUILDING BLOCK REQUIREMENTS

• TRANSPORTATION	Shuttle and large tug or SEPS
• ON-ORBIT OPERATIONS	Automated or manual servicing unit; assemble in orbit
• SUBSYSTEMS	Attitude control; antenna; RF power DC power, channelized transponder
• TECHNOLOGY	Large multibeam antenna; power tubes; channelization techniques; large-scale multiple access
• OTHER	

Figure 4-9. Vehicular Speed Limit Control (CS-10)

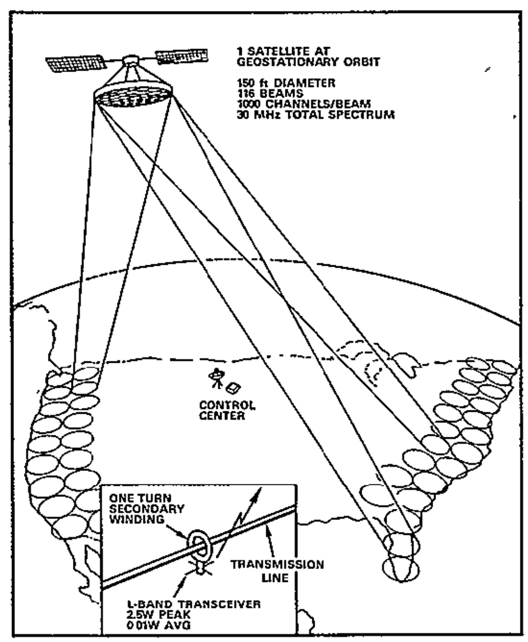
In this concept, the ground control center queries each car's set as to its location, determines the speed limit appropriate for that location, and commands the proper governor setting. This is repeated in a sequence, rapid enough that one million cars can be controlled in each of 100 urban areas (100 million cars total). The speed limit zones are easily changed by a computer program change.

The last initiative concept discussed under the category of civic applications, though having other applications as well, is that of real-time remote monitoring of the consumption and flow of energy, in order to allow large-scale programming of energy flow, or determination of compliance with energy use-curtailment ordinances.

- **PURPOSE**
  To measure energy flow at a very large number of points on distribution network.
- **RATIONALE**
  Power programming and fine-tuning requires knowledge of energy status on network.
- **CONCEPT DESCRIPTION**
  Small L-band transmitters send instantaneous current, voltage, or power readings on network when queried sequentially by multi-channel/processing communications repeater.
- **CHARACTERISTICS**

• WEIGHT	10,000 lb
• SIZE	150-ft dia
• RAW POWER	23 kW
• ORBIT	Geostationary
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1990
• IOC COST (Space only)	300 M

- **PERFORMANCE**
  Up to one billion points on energy generation and distribution network measured every hour.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and IUS/tug
• ON-ORBIT OPERATIONS	Automated or manual servicing, assembly
• SUBSYSTEMS	Attitude control, antenna, processor
• TECHNOLOGY	Multi-channel transponder, LSI processor
• OTHER	

Figure 4-10. Energy Monitor (CS-9)

This initiative, illustrated in Figure 4-10, utilizes a similar low risk satellite to that of Figure 4-8, and reads out to one or several control centers information on the status of energy flow in an extremely large number of points in the distribution network. The voltage, current, power flow, and power factor can be used for the electrical network, or the analogous quantities of pressure velocity, etc., readout for hydraulic or gaseous energy distribution networks. In the illustrated concept, over one billion points on the network can be monitored, enabling real-time control, power programming, power sharing, etc. This concept is clearly also applicable to U.S.-wide use.

The initiatives illustrated show some ways in which space could aid local governments in law enforcement, traffic safety, disaster control, energy ordinance enforcement, local elections and hearings, and many other functions.

4.1.3 Industrial Applications

The potential applications to industry are many and varied and most hold a potential to aid in increasing profits, expanding business lines into potentially highly profitable ventures, compliance with energy and pollution laws, and generally assuring continued and increased return to the investing capital. The initiatives discussed under this category include:

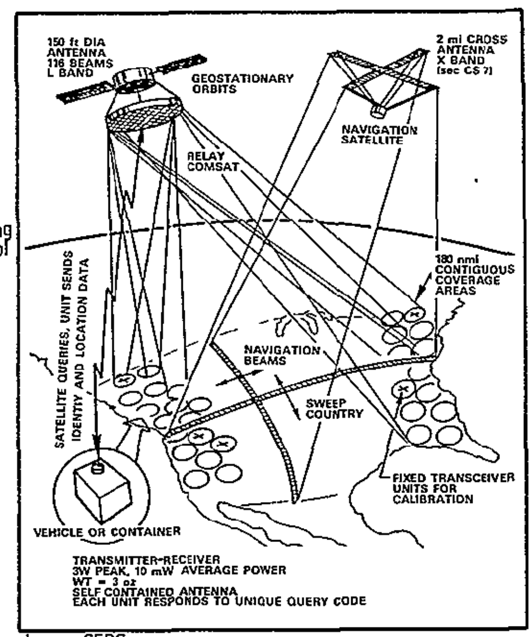
1. Vehicle/Package Locator
2. Advanced T. V. Broadcast
3. 3-D Holographic Teleconferencing
4. Advanced Resources/Pollution Observatory
5. Energy Monitor
6. Burglar Alarm/Intrusion Detection

The first concept discussed in this applications class is that of a system to aid in locating "lost" vehicles or packages, or to aid in the prevention of their theft or hijacking. The railroad industry might benefit from being able to instantly and continuously locate and identify all rail-road cars; the rental car companies might also, to a lesser extent; thefts, losses, unaccounted disappearances, and many delays due to errors in routing of packages, crates, and other items shipped by car, rail, truck, train, car, or ship could also be minimized by location determination on a continuous or on-demand basis. All of these applications could be satisfied by "tagging" each vehicle or item shipped with a small radio set whose position could be determined at will from space on a periodic or continuous basis. One approach to such transshipment package or vehicle locators is illustrated in Figure 4-11. This concept is similar to that of the vehicle speed control system illustrated in Figure 4-9, in that it capitalizes on the ability of each vehicle or package to determine its own position with a tiny, inexpensive receiver utilizing the "personal navigation" type of satellite (Figure 4-4). It is then a simple matter to report the position to the dispatch control center upon query.

- **PURPOSE**
  To locate vehicles or articles in shipment continuously anywhere in U. S. A.
- **RATIONALE**
  To aid in prevention of theft or hijacking, increase efficiency, and minimize error in shipments
- **CONCEPT DESCRIPTION**
  A small transceiver is attached to (or enclosed in) each unit to be tracked. The unit determines its location using crossed antenna NAVSAT, and relays the data to a control center via a special Comsat when queried.
- **CHARACTERISTICS**

• WEIGHT	20,000 lb (Total)
• SIZE	2-mi antenna
• RAW POWER	23 kW
• ORBIT	Geostationary
• CONSTELLATION SIZE	2
• RISK CATEGORY	II (Medium)
• TIME FRAME	1990
• IOC COST (Space only)	400 M

- **PERFORMANCE**
  Up to one billion vehicles or containers can be located ± 300 ft every hour anywhere in U. S. A. Location package could cost less than $10, weigh 3 ounces.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and large/tandem tug or SEPS
• ON-ORBIT OPERATIONS	Automated or manned assembly and servicing
• SUBSYSTEMS	Antenna attitude control, laser radar, channelizer/processor, stationkept antenna
• TECHNOLOGY	Phase control, LSI processor, multiple access technique, stationkept sub-units
• OTHER	Cheap - LSI - container - transponder

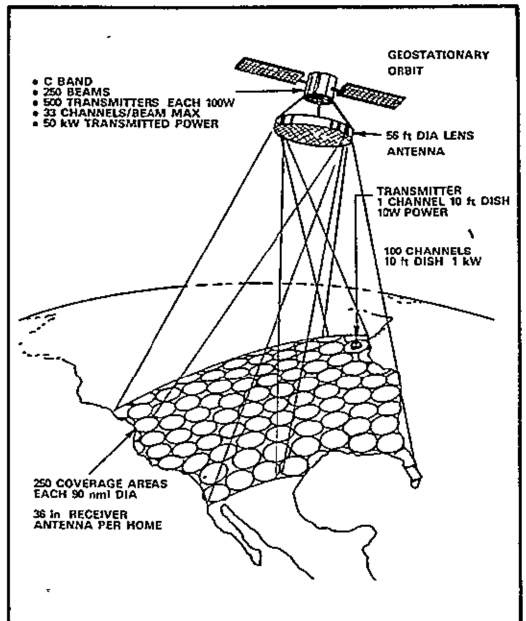
Figure 4-11. Vehicle/Package Locator (CC-12)

An extremely large number of vehicles or packages can be tracked using such a system, since a simple code query and reply need not take more than a small fraction of a second permitting up to one billion per hour in the illustrative example to be located to an accuracy better than 300 ft in all kinds of weather and 24 hours a day. Applications such as the above are categorized as medium risk if they use the 2-mile long antenna navigation satellite. They would be considered lower risk if they were so designed as to depend on nearer-term technology for location determination, such as Loran receivers, etc. This application, as many of the previous ones, allows services to many tiny and inexpensive user sets by virtue of transferring much of the complexity and size to the space segment, in keeping with the general perspectives discussed in Section 3.

Mass communications, education, and entertainment media can greatly benefit from direct T. V. broadcast to the home from space. Starts along such a direction are currently being made in domestic satellites to back up or replace microwave tower links, but generally do not have the power to reach small receiver antennas in the home, and thus will reach larger community antennas and be distributed locally. An advanced T. V. broadcast satellite initiative is therefore shown, illustrated in Figure 4-12, which allows over 500 channels of color T. V. to be distributed to the entire country, 33 channels maximum to any one region, with flexibility to allow power-density programming in accordance with population density. Furthermore, the home receiver antenna need only be 36 in. in diameter, point almost straight up, be non-tracking, and can be placed inside the set, attic, or on the roof. This is due to the 50 kW of power and 56-ft antenna in the satellite. With satellite relay of this power, there would be no "fringe areas" of poor or marginal reception anywhere in the country, and small T. V. stations could originate local programs and distribute them anywhere with only a 10-ft antenna to access the satellite. Despite the power requirements, the satellite is still felt to be low risk, requiring only the paralleling of output tubes and solar cells.

Most travel to other cities to attend meetings is expensive, time consuming, energy consuming, and disruptive to the home life. It is now possible to send three-dimensional image "holograms" of the parties which wish to conference to and from identical conference rooms, each fitted with

- **PURPOSE**
  To make T.V. available to all locations in U.S., with small receiver antennas.
- **RATIONALE**
  Mountainous, rural, and remote areas currently have poor or no service due to line-of-sight transmissions.
- **CONCEPT DESCRIPTION**
  Powerful satellite in geostationary orbit makes reception possible in all U.S. areas with very small antennas.



- **CHARACTERISTICS**

• WEIGHT	14,000 lb
• SIZE	56-ft antenna
• RAW POWER	150 kW
• ORBIT	Geosynchronous
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1990
• IOC COST (Space only)	460 M

- **PERFORMANCE**
  512 color T.V. channels broadcast to U.S. land area, covered in 250 beams, each with 90-mi footprint. Local stations can distribute program anywhere.
- **BUILDING BLOCK REQUIREMENTS**

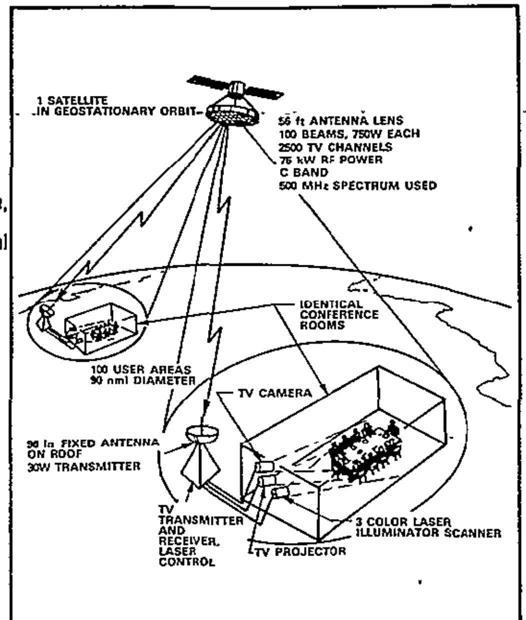
• TRANSPORTATION	Shuttle and large tug or SEPS
• ON-ORBIT OPERATIONS	Automated or manned servicing
• SUBSYSTEMS	100 W output tube, 60-ft multibeam antenna
• TECHNOLOGY	Processor/filters
• OTHER	None

Figure 4-12. Advanced T.V. Broadcast (CC-6)

a multicolor laser illuminator, a "T.V." camera, and a "T.V." projector. The interference holograms picked up by the camera would be transmitted via a special communication satellite, illustrated in Figure 4-13, and be projected into the receiving room, mixing with the laser illuminator to produce images.

The images received will appear completely lifelike, in color, in true three-dimensional depth and perspective, and will move around, speak, and be otherwise identical to live people except they will not contain matter. Reports can be reviewed, close scrutiny of objects such as letters accomplished, presentations made and reviewed, and essentially all functions of conferences satisfied except for shaking hands. The satellite requirements are to simultaneously relay as many T.V. channels as possible. The illustrated design is capable of relaying 2,400 simultaneous T.V. channels with ground terminals with only 96-in. antennas and 30 watts of power on the rooftop of buildings. One thousand two hundred and fifty simultaneous

- **PURPOSE**
  To greatly reduce the need to travel for most government or private industry business conferences without significant loss in ability to transact business
- **RATIONALE**
  Travel for conferences is costly, time consuming, and inefficient.
- **CONCEPT DESCRIPTION**
  Identical conference rooms are fitted with a T.V. camera, T.V. projector, and laser illuminator and stereo sound system. Resulting holograms produce three-dimensional images that can walk, talk, and present data.
- **CHARACTERISTICS**
  - WEIGHT: 15,000 lb
  - SIZE: 56-ft antenna
  - RAW POWER: 220 kW
  - ORBIT: Geostationary
  - CONSTELLATION SIZE: 1
  - RISK CATEGORY: III (Medium)
  - TIME FRAME: 1990
  - IOC COST (Space only): 500 M
- **PERFORMANCE**
  1,250 identical conference rooms in 100 urban areas interconnected simultaneously with 3-D color holographic images and stereo sound.



- **BUILDING BLOCK REQUIREMENTS**
  - TRANSPORTATION: Shuttle, large/tandem tug or SEPS
  - ON-ORBIT OPERATIONS: Automated or manual assembly and servicing
  - SUBSYSTEMS: Large multibeam antennas, processors, high power transmitter
  - TECHNOLOGY: High power transmitters - LSI processors, prime power source
  - OTHER: User equipment, holographic quality, image motion compensation

Figure 4-13. 3-D/Holographic Teleconferencing (CC-11)

conferences can thus be handled, with larger numbers requiring only larger or more satellites. The risk is medium because of the uncertain requirements on the camera, laser, and projector.

Holographic teleconferencing has the potential to change the entire fabric of our society. In the very far term this capability could result in the elimination of office buildings, allowing white collar workers to "work" out of their homes yet be in "person-to-person" touch with anyone, anywhere, anytime.

Both the advanced T. V. and the holographic teleconferencing require large communication satellites whose main unusual requirements are high power, large number of channels, large multibeam antenna, and complex addressor-addressee switching. Larger orbital transfer stages than now exist will be required, as will orbital servicing.

Industry could additionally benefit from data obtained from high resolution ground observation satellites such as described under "government applications," to aid in exploration for resources such as oil and minerals, pest control, monitoring plant pollution output, geological surveys for plant siting, and many other uses.

Industry could also use the energy monitor capability and the burglar alarm/intrusion detection capability described in Figures 4-10 and 4-8 respectively under civic applications, as well as several other initiatives in this report.

4.1.4 Government Applications

A large number of initiatives were collected for application primarily by the Federal Government. Though some also find application at the local government, industrial, and personal levels, many are either very large, involve interstate services, or are intended to make government itself function more effectively and thus they were included in this application category for the purposes of this report. The government applications will be discussed under a categorization scheme of communications, observation, and support. The initiatives discussed include:

Observation (Section 4.1.4.1)

1. Advanced Resources/Pollution Observation
2. Water Level and Fault Movement Indicator
3. Atmospheric Temperature Profile Sounder
4. Synchronous Meteorological Satellite
5. Fire Detection
6. Ocean Resources and Dynamics System

Communications (Section 4.1.4.2)

1. Global Search + Rescue Locator
2. Transportation Services Satellites
3. Voting/Polling Wrist Set
4. Vehicle/Package Locator
5. 3-D Holographic Teleconferencing
6. Electronic Mail Transmission
7. National Information Services
8. Nuclear Fuel Locator
9. Personal Navigation Wrist Set
10. Border Surveillance
11. Burglar Alarm/Intrusion Detector

Support (Section 4.1.4.3)

1. Coastal Anti-Collision Passive Radar
2. Rail Anti-Collision System
3. Night Illuminator
4. Energy Generation - Solar/Microwave
5. High Efficiency Solar Energy Generation
6. Energy Generation - Nuclear/Microwave
7. Multinational Energy Distribution
8. Aircraft Laser Beam Powering
9. Energy Monitor
10. Nuclear Waste Disposal
11. Space Debris Sweeper
12. Ozone Layer Replenishment/Protection

4.1.4.1 Observation

A number of initiative concepts are described whose main purpose is the observation of phenomena on the earth. The chief advantages of observation from space are coverage and coverage rate, which in the past and present could only be obtained simultaneously with high spatial and spectral resolution by low-altitude satellites. In the future, the advent of charge-transfer-devices will make possible detector mosaics with millions of tiny detectors which, coupled with large optics will allow both high resolution and high coverage rate, and will probably allow them to be obtained from synchronous altitudes as well.

The first area discussed included initiatives intended for high resolution, multispectral imaging, or all weather mapping of surface features for resources search, pollution identification, insect control, forest management, and other allied functions. The initiative which describes the capability is illustrated in Figure 4-14, and is a larger, higher resolution version of the current Landsat earth resources satellite. It features multispectral optics combined with a synthetic aperture array radar, for obtaining simultaneous imagery at several resolutions from 10 - 100 ft in many spectral regions 24 hours a day and through all weather. The satellite, though an order of magnitude heavier than current generation satellites, is a low risk near-term system requiring only the shuttle for boost and orbital servicing.

- **PURPOSE**

  To provide high quality, multispectral earth resources and pollution data.

- **RATIONALE**

  Integrated ERTS-like system, real-time data distribution to worldwide users, active sensors needed.

- **CONCEPT DESCRIPTION**

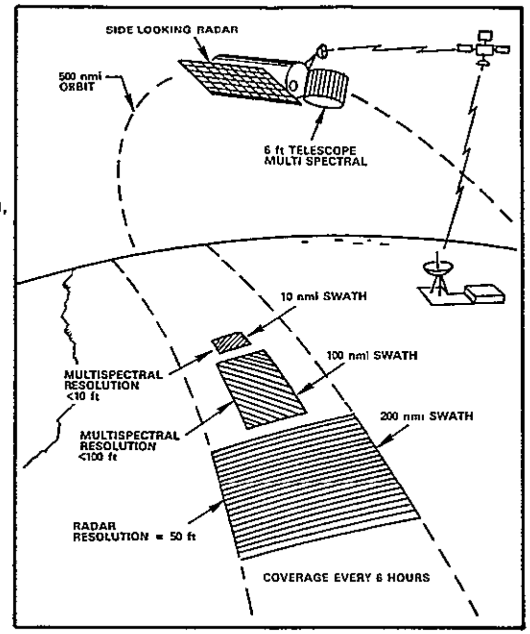
  Active and passive sensors, large aperture, high, medium, and low resolution imaging obtained in multispectral region and radar. Data disseminated by laser link through relay satellite.

- **CHARACTERISTICS**

• WEIGHT	30,000 lb
• SIZE	10 x 60 ft
• RAW POWER	12 kW
• ORBIT	500 nmi sun synch.
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1985
• IOC COST (Space only)	350 M

- **PERFORMANCE**

  Multispectral resolutions varying from < 10 to < 100 ft obtained worldwide.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and tug
• ON-ORBIT OPERATIONS	Shuttle attached manipulator, servicing stages
• SUBSYSTEMS	Guidance and navigation; attitude control; transmitter
• TECHNOLOGY	Large radar antenna; high power tubes and modulator; LSI data processor
• OTHER	None

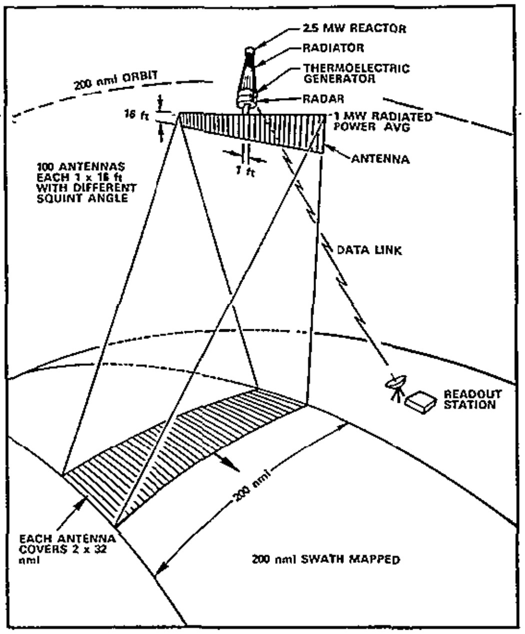
Figure 4-14. Advanced Resources/Pollution Observation (CO-1)

Much improved resolution is probably possible, both in the optical and microwave regimes, with atmospheric scintillation setting the attainable limit, at least in the optical regime. Much larger optical mirrors, coupled with pulsed laser illumination, may be able to reduce the effects of scintillation, but the extent to which such can be reduced is not established. An initiative concept is therefore described which provides increased resolution in the microwave area. It is illustrated in Figure 4-15, and is a pure synthetic array radar of about one megawatt average power, with which surface resolution of better than a few feet should be readily obtainable. In the illustration, a swath of 200-nmi width is mapped, though for the same total power, further increases in resolution performance should be obtainable at the expense of swath width. A reactor power source would probably be required, but the space radar is a relatively straightforward extension

- **PURPOSE**
  To provide maps of the surface with high resolution through cloud cover.
- **RATIONALE**
  -Resources; pollution, crop, water, and other observations may be aided by high resolution and frequent coverage regardless of weather.
- **CONCEPT DESCRIPTION**
  Synthetic array radar of very high power provides high resolution. On-board image processing allows microwave data link for all weather capability.
- **CHARACTERISTICS**

• WEIGHT	110,000 lb
• SIZE	16 x 100 ft
• RAW POWER	2.5 MW
• ORBIT	200 nmi polar
• CONSTELLATION SIZE	1
• RISK CATEGORY	II (Medium)
• TIME FRAME	1990
• IOC COST (Space only)	500 M

- **PERFORMANCE**
  200 nmi ground swath mapped to less than a few feet resolution once a day. U S. covered every six days.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle
• ON-ORBIT OPERATIONS	Shuttle manipulator; servicing
• SUBSYSTEMS	Thermal, nuclear, power generator, radar
• TECHNOLOGY	High power transmitter; automated image processor, reactor, shielding
• OTHER	None

Figure 4-15. High Resolution Earth Mapping Radar (CO-13)

of current techniques, differing primarily in power output. This concept is therefore placed in Risk Category II, requiring considerable development and orbital demonstration.

The utility of such a fine resolution in the resources/pollution/farming/forestry functions is not known to the study team, but it seems likely that the question has not been adequately explored in the past, it not being seriously considered.' However, systems with such or better resolution could advent a capability to accurately predict crop yield over large and diverse farm areas by actually counting the number of ears of corn per acre (for example), identifying the number and location of plants affected by disease, counting the number of livestock larger or smaller than a given size, and many other capabilities which may only become apparent upon reflection. Of course, the data processing to intelligently use and disseminate the hugh amounts of data from any such ability must be enormously capable. It is assumed, as discussed in Section 3, that such computing power will exist.

Assembly or initialization of the satellite, as well as servicing and "tweaking" or peaking for optimum performance are requirements. The Space Shuttle could perform well as a booster, and base for assembly and servicing on orbit. It must be emphasized again that such an observation capability is not being advocated nor that it would clearly be useful if available, but rather that its potential availability should be considered by the earth-observation community.

The rest of the material on observation will deal with initiatives whose function is other than the simple imaging of the surface. The first initiative addresses the obtaining of precise relative range measurements.

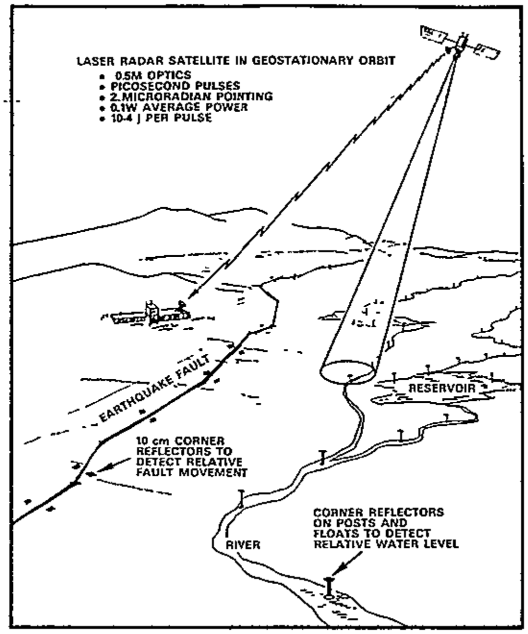
Recent advances in mode-locked lasers make possible the generation and detection of pulses of picosecond duration (10^{-12} sec), which herald a subsequent ability of ranging to an accuracy of 0.3 millimeters ($\approx$ 10/1000 in.) essentially independent of range. By emplacing corner reflectors on both sides of earthquake fault lines, relative movements of such magnitudes could be detected from satellites equipped with mode-locked lasers, and utilized for earthquake prediction. Similarly, relative range could be obtained to fixed and floating reflectors on bodies of water, resulting in extremely sensitive remote water height measurements for flood, drought, or water resource predictions.

The real advantage of making such measurements from space rather than from ground or aircraft, is the enormous number of measuring points which can be accessed in very short periods of time by the same calibrated instrument, thus obtaining large-area patterns nearly simultaneously yet combined with finely detailed individual observations. An initiative concept illustrating such an application is illustrated in Figure 4-16. In this illustration it is seen that a small, lightweight satellite can measure in excess of 100,000 points anywhere in the U.S.A. (or almost a hemisphere) in one hour, with the same basic accuracy for all points. This is a low risk system which probably could be orbited in the mid 80's using no more than a shuttle and IUS or Tug. Orbital servicing could be performed at synchronous or low altitude.

- **PURPOSE**
  To make precision measurements in many places in rapid succession for aid in earthquake prediction, water resources establishment, disaster use, etc.
- **RATIONALE**
  Prediction of earthquakes, floods, droughts, and accurate water resources would be of great social and economic benefit
- **CONCEPT DESCRIPTION**
  Picosecond (10^{-12} sec) pulsed laser radar in orbit obtains precision differential range measurements from corner reflectors implaced on both sides of faults, river banks and floats, etc.
- **CHARACTERISTICS**

• WEIGHT	800 lb
• SIZE	0.5 m optics
• RAW POWER	250 W
• ORBIT	Geostationary
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1985
• IOC COST (SPACE ONLY)	50 M

- **PERFORMANCE**
  Relative range obtained to $\pm$ 0.03 millimeters at any number of points separated by 100 meters or more. 10^5 instrumented points can be measured every hour.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle, IUS/Tug
• ON-ORBIT OPERATIONS	Automated or manned servicing
• SUBSYSTEMS	Picosecond receiver, transmitter, 2 μr pointing
• TECHNOLOGY	Streak camera converter, mode locked laser and switch
• OTHER	

Figure 4-16. Water Level and Fault Movement Indicator (CO-3)

Other applications of satellite-borne mode-locked lasers include the "imaging" of objects with range profile without requiring high angular resolution; sea-state measurements, etc.

The use of small pulsed lasers as vertical "sounding" instruments could give precise worldwide measurements of atmospheric temperature (and perhaps pressure) profiles on a periodic basis with a measurement resolution of 100 ft or so in the vertical dimension, obtaining the profile directly rather than by unfolding and inferring total-vertical-path measurements such as done today. Figure 4-17 illustrates such an initiative in which atmospheric molecules are excited by the laser, and the rotational transitions upon their relaxation are detected by a millimeter wave receiver on board the satellite. The ratio of the intensity of various emission lines is relatable to the rotational temperature, while their width should be relatable to the pressure of the gas. Range gating of the receiver

- **PURPOSE**
  To measure actual profiles of temperature in the atmosphere.

- **RATIONALE**
  Weather prediction requires knowledge of temperature profiles, as well as other phenomena.

- **CONCEPT DESCRIPTION**
  Pulsed laser vibrationally excites CO_2 or H_2O molecules. Subsequent rotational transitions in the millimeter wave spectrum show temperature dependence which is measured by ratio of energy in several lines.

- **CHARACTERISTICS**

• WEIGHT	4000 lb
• SIZE	30-ft dia antenna
• RAW POWER	5 kW
• ORBIT	600-nmi polar
• CONSTELLATION SIZE	4
• RISK CATEGORY	III (Medium)
• TIME FRAME	1990
• IOC COST (SPACE ONLY)	250 M

- **PERFORMANCE**
  Entire atmosphere measured, with resolution of 300 ft horizontally and 100 ft vertically, every four hours. Emission lines and signal strength imprecisely defined at present.

- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and tug/IUS
• ON-ORBIT OPERATIONS	Automated service unit/Shuttle-attached manipulator
• SUBSYSTEMS	Antenna, laser, attitude control
• TECHNOLOGY	Laser, power dissipation, antenna, pointing, sensitive heterodyne receiver
• OTHER	

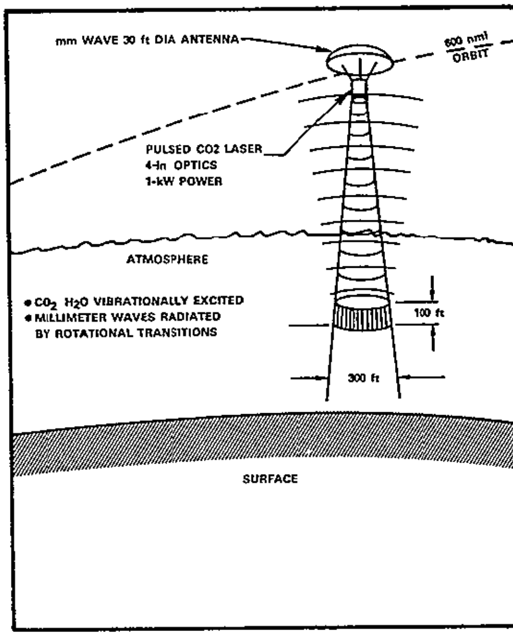


Figure 4-17. Atmospheric Temperature Profile Sounder (CO-11)

should be able to select out signals from only the desired volume of the atmosphere. There is considerable risk in this concept, however, not because of the technology involved, but rather due to the uncertain signal strength obtainable compared to the applicable noise, and the lack of precise data on the strengths of the emission lines. It is for this reason that this initiative has been placed in Category III, signifying that the exact numbers pertaining to the phenomena need calculation and/or verification.

The ability to orbit large and massive payloads at synchronous altitudes can result in optical observation systems whose resolution is identical with that of current low-altitude satellites, but with the ability to cover any area in almost half the earth in a continuous mode. All that is required, in principle, is an optical diameter 100 times that of a 200 nmi altitude satellite. A typical example of such capability could be a synchronous altitude meteorological satellite such as illustrated in Figure 4-18, in which a telescope with 3-ft diameter optics obtains a 300 x 300 ft resolution for

- **PURPOSE**
  To collect worldwide atmospheric data for global weather prediction.
- **RATIONALE**
  High resolution and frequent coverage of globe are needed for forecasts.
- **CONCEPT DESCRIPTION**
  Optical sensor with 1 meter mirror collects visible light data on gross meteorological features. Same instrument makes spectrum measurements for detailed information on atmosphere.
- **CHARACTERISTICS**
  - **WEIGHT** 3,000 lb
  - **SIZE** 5 x 30 ft
  - **RAW POWER** 1 kW
  - **ORBIT** Synch. Equat.
  - **CONSTELLATION SIZE** 3
  - **RISK CATEGORY** 1 (Low)
  - **TIME FRAME** 1985
  - **IOC COST** (Space only) 190 M
- **PERFORMANCE**
  Ground resolution 300-ft dia. Scan rate: earth coverage in 20 sec for clouds, etc Detailed measurements of spectrum every 200 sec.
- **BUILDING BLOCK REQUIREMENTS**
  - **TRANSPORTATION** Shuttle and tug
  - **ON-ORBIT OPERATIONS** Automated or manual servicing unit
  - **SUBSYSTEMS** Laser for communications
  - **TECHNOLOGY** Laser communications link. LSI computer
  - **OTHER** Weather prediction algorithm

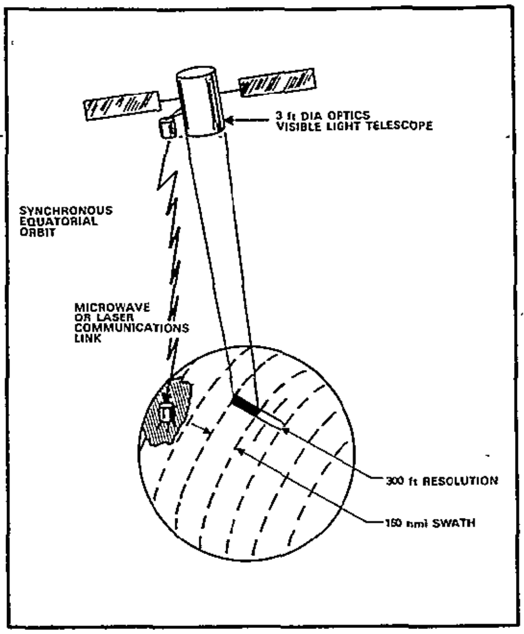


Figure 4-18. Synchronous Meteorological Satellite (CO-12)

synoptic as well as local meteorology. The satellite is not heavier or larger than some current satellites, and represents a near-term capability of low risk, requiring only the Shuttle and IUS/Tug and automated servicing for long life. A similar satellite with somewhat larger optics can function as a forest fire lookout to observe all the U.S. land mass and report instantaneously the starting of even small fires so that grass, prairie, forest, and even city fires can be essentially instantaneously detected and rapidly brought under control, minimizing loss of property and life. Such an initiative is illustrated in Figure 4-19. In this initiative, an infrared telescope of 10-ft diameter with advanced mosaic detector focal plane scans the U.S.A. every 2.5 minutes to perform the function. The satellite is expected to weigh 25,000 lb or so, but comprise a low-risk development nonetheless. The support requirements are met by a shuttle and appropriate orbital transfer vehicle such as a larger version of the full capability tug,

- **PURPOSE**

  To detect fires in remote regions, maintain surveillance of hot spots, fire perimeters.

- **RATIONALE**

  Fire damage can be minimized by early detection, and firefighting with knowledge of extent and progress.

- **CONCEPT DESCRIPTION**

  Satellite with short and long wave infrared sensors detects fires at an early stage - transmits data to control center.

- **CHARACTERISTICS**

• WEIGHT	25,000 lb
• SIZE	15 x 60 ft
• RAW POWER	2 kW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1985
• IOC COST (Space only)	230 M

- **PERFORMANCE**

  Detects fires as small as 10 x 10 ft Location accuracy < 300 ft. Resolution = 300 ft - U. S. coverage every 2 1/2 minutes.

- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and large tug
• ON-ORBIT OPERATIONS	Automated or manual servicing unit
• SUBSYSTEMS	Attitude control; sensor
• TECHNOLOGY	Large optical mirror; LSI data processor; CCD focal plane
• OTHER	None

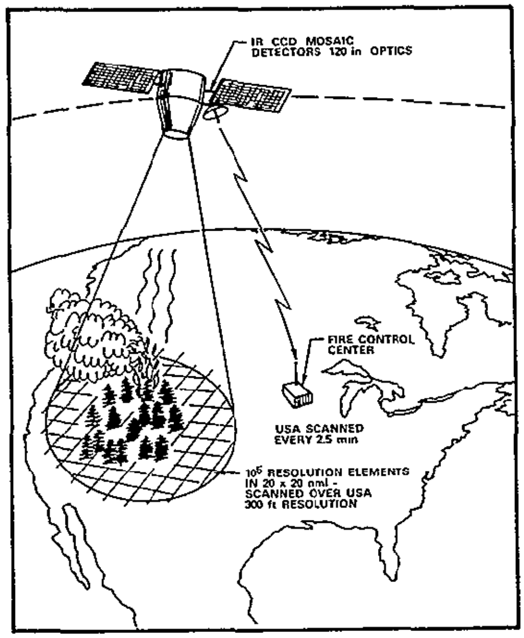


Figure 4-19. Forest Fire Detection (CO-2)

or a solar-electric stage, though assembly in orbit would allow use of an IUS or standard tug. Servicing in orbit would be called for to maximize use of the investment.

A last example of the potential utility of large optical devices for observation of the earth is the orbiting of telescopes in which the detectors and perhaps even the optics are cryogenically cooled in order to operate in the 8-22 micrometer wavelength range. In this spectral region, the instrument will be sensitive to the self-emission of bodies on the earth, and will "read" tiny differences in surface temperature or emissivity in sea water. One initiative application is shown in Figure 4-20, in which water temperature differences as small as 0.002 deg yield a detectable signal. Such differences could be relatable to the surface disturbances caused by large schools of fish close to the surface, or to the presence of plankton or other factors associated with food supply, which could be

- **PURPOSE**
  To locate schools of fish and to map ocean dynamic signatures.
- **RATIONALE**
  Fish protein resource yield needs to be maximized due to world protein shortage. Mapping instruments needed.
- **CONCEPT DESCRIPTION**
  Temperature and emissivity differences in surface water caused by schools of fish, currents, and plankton concentrations are detected by the differences in their self-emission in the long-wave infrared
- **CHARACTERISTICS**

• WEIGHT	15,000 lb
• SIZE	10 x 60 ft
• RAW POWER	25 kW
• ORBIT	300 nmi polar
• CONSTELLATION SIZE	1
• RISK CATEGORY	1 (Low)
• TIME FRAME	1985
• IOC COST (SPACE ONLY)	300 M

- **PERFORMANCE**
  100-ft resolution attained over all ocean surfaces every 12 hours. Sensitivity equivalent to 0.002 deg C achieved.
- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle
• ON-ORBIT OPERATIONS	Shuttle attached manipulator
• SUBSYSTEMS	Thermal dissipation, sensor, cryogenic cooler
• TECHNOLOGY	Large LWIR sensor: cryogenic refrigerator; LSI data processor
• OTHER	None

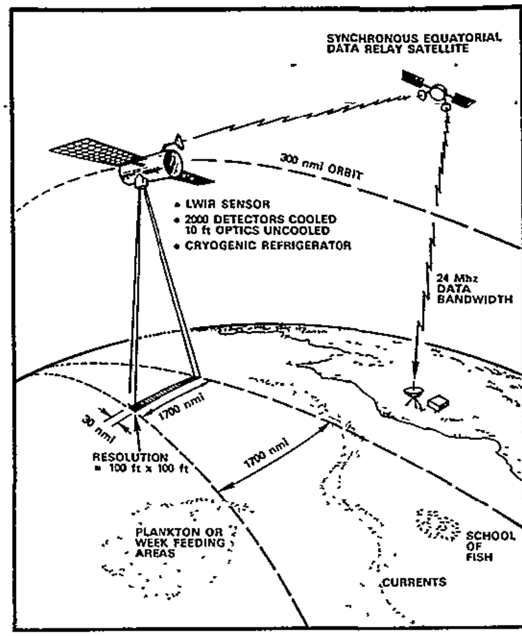


Figure 4-20. Ocean Resources and Dynamics System (CO-4)

correlatable to fish resources and used for increasing or at least predicting the "catch" for ocean farming. Ocean dynamics such as currents will be clearly visible for increased precision and insight in oceanography. Ocean pollution such as the extent of oil spills can be mapped with precision and its course predicted. The advantage of such capability over similar airborne sensors would be the coverage of all ocean areas every 12 hours from a single satellite. The illustrated initiative uses a data relay satellite to send the raw or semi-processed data to the U.S. or other readout stations for processing and distribution. This satellite again weighs about 30,000 lb, but is a relatively low development risk. It can be orbited by the shuttle, and serviced periodically by an attached manipulator or in the shuttle bay.

4.1.4.2 Communications

Many interesting government applications exist for communications initiatives. Some initiatives already described under personal, industrial, or civic applications clearly could also serve the Federal government, and they will be mentioned as well as ideas which really best serve or involve interstate services.

The first initiative is a concept for search and rescue location system to be used on a global basis for location of downed aircraft, ships in distress, and many allied though less recognized applications. In the illustration on Figure 4-21, a small emergency transmitter carried by aircraft, ships, boats, etc., radiates one-watt signals which are picked up and retransmitted by three or four satellites out of a worldwide constellation of 20 satellites. The time-difference-of-arrival of the retransmitted signals at one of several ground centers yields the position of the transmitter to better than 500-ft accuracy and functions in all-weather, 24 hours a day. The transmitter package can be small, weighing less than 1 lb and still transmit continuously for one month.

This is a near-term low risk concept with conventional satellites. Appropriate coding can assure the accommodation of at least 1,000 simultaneous emergency signals worldwide on a single kHz channel. The advantage of using space is that of worldwide continuous coverage with no blind spots.

- **PURPOSE**
  To locate emergency transmitters worldwide; to allow small, lightweight transmitters
- **RATIONALE**
  Search for rescue is expensive and not always successful
- **CONCEPT DESCRIPTION**
  Coded, small transmitter in emergency package carried by traveling boats, aircraft. Signals received and transponded by satellites, and location computed by TDOA techniques
- **CHARACTERISTICS**
  - WEIGHT 1500 lb
  - SIZE 5 x 20 ft
  - RAW POWER 1 kW
  - ORBIT Near-Synch., or Med Alt.
  - CONSTELLATION SIZE 20
  - RISK CATEGORY I (Low)
  - TIME FRAME 1985
  - IOC COST (Space only) 350 M
- **PERFORMANCE**
  Location of up to 1000 simultaneous emergency transmitters to 500 ft in three coordinates, anywhere, worldwide
- **BUILDING BLOCK REQUIREMENTS**
  - TRANSPORTATION Expendable or shuttle and tug
  - ON-ORBIT OPERATIONS Automated servicing unit
  - SUBSYSTEMS No unusual requirements
  - TECHNOLOGY No unusual requirements
  - OTHER None

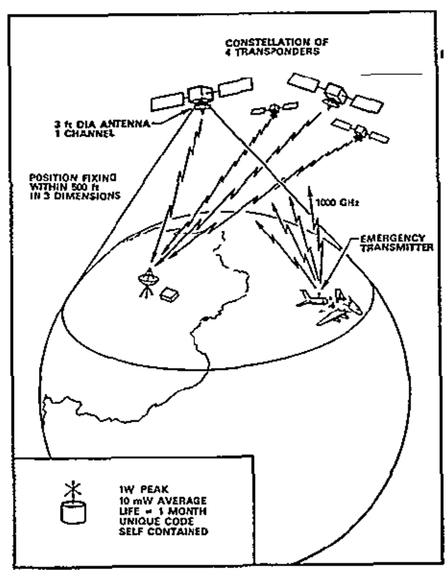


Figure 4-21. Global Search + Rescue Locator (CC-1)

An extension of the previous concept is to place receivers as well as transmitters aboard each aircraft or other vehicles under government jurisdiction and perform remote traffic surveillance, self-navigation, and two-way digital communications, all using the same equipment. This concept is illustrated in Figure 4-22. The techniques and devices could be very similar to that being procured for the Global Positioning System by the Defense Department, and performance accuracies would surpass any other form of navigation. The satellites would have to transpond rather than merely transmit signals, but be otherwise identical. This would also be a near-term low risk system which could serve many government agencies concerned with transportation. The support requirements are for a shuttle (or expendable) and an IUS or tug. Automated servicing in high orbit or manual servicing in the shuttle would be called for.

- **PURPOSE**
  Simultaneously satisfy traffic control, air surveillance, navigation, position fixing, command/control for multiplicity of uses.
- **RATIONALE**
  Similar and overlapping requirements by many agencies for precision navigation enable one comprehensive system to meet all needs for all users.
- **CONCEPT DESCRIPTION**
  Comsat transponders are used, with four in view of user at different angles/ranges, to provide TDOA position fixing and 2-way communications.
- **CHARACTERISTICS**
  - WEIGHT: 1400 lb
  - SIZE: 6 x 8 ft
  - RAW POWER: 600 W
  - ORBIT: 8000 nmi polar
  - CONSTELLATION SIZE: 20
  - RISK CATEGORY: I (Low)
  - TIME FRAME: 1985
  - IOC COST (Space only): 350 M
- **PERFORMANCE**
  100,000 users serviced; position to 30 ft, surveillance of beacon to 100 ft, digital communications of 100 kb/sec.
- **BUILDING BLOCK REQUIREMENTS**
  - TRANSPORTATION: Expendable or shuttle and tug
  - ON-ORBIT OPERATIONS: Automated servicing unit
  - SUBSYSTEMS: No unusual requirements
  - TECHNOLOGY: No unusual requirements
  - OTHER: None

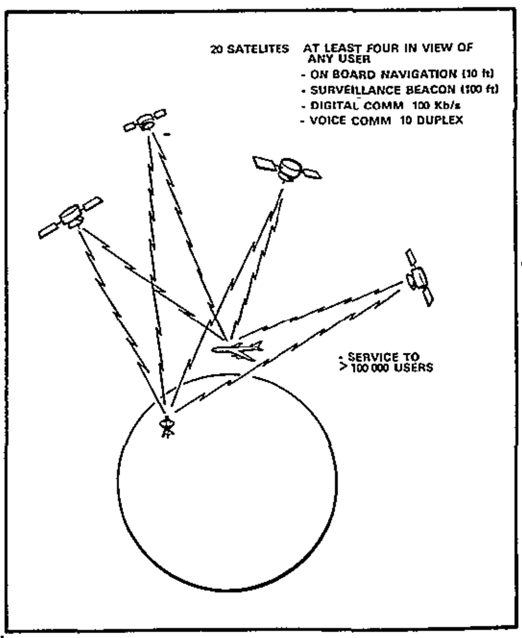


Figure 4-22. Transportation Services Satellites (CC-5)

Three initiatives discussed previously bear mentioning again, specifically for government applications. The first is the personal wrist radio voting and polling set which was illustrated in Figure 4-3. The obvious government use is for federal elections, and use by federal elected representatives for guaging public opinion on a variety of issues. The possibilities for a more participatory democracy are self-evident. The second initiative is the vehicle/package locator which was illustrated in Figure 4-11. Not only could GSA maintain better inventory of its motor pool, but all high value or sensitive government documents or packages being shipped could be tagged (such as classified documents, certain parts and equipment, registered/certified mail, and any other property which should be locatable on demand) and is subject to wide ranging transport. The third initiative is that of the 3-dimensional (holographic) image teleconferencing, which was illustrated in Figure 4-13. Wide-scale application of this concept could improve the efficiency of government operations by reducing the need to travel without reducing the degree of involvement by its officials. In fact, since teleconferencing by microphone and loudspeaker is already operational in several government agencies, the progression to teleconferencing by image transmission is but a logical step along a path already being traversed by the federal government.

In this age of electronics and communication satellites, there really need not be a requirement that the bulk of information be sent in its physical form by the Postal Service. In fact, the use of a single satellite with 200-ft multibeam lens antenna could make possible electronic transmission of mail by the Postal Service in which letters would be "read" by automatic scanners much like T.V. cameras in the originating post offices, with hard copy printing and sealing at the receiving post offices, at the rate of 100 billion of pages per day. The letters would then be delivered by normal carrier. This initiative is illustrated in Figure 4-23. The local post office would only require a 3-ft antenna (no larger than that used for commercial home television reception), and cheap radio terminal equipment not unlike a citizens band transmitter/receiver. Such a system

- **PURPOSE**
  To speed up delivery and lower costs of most mail.
  To service thinly populated areas.
- **RATIONALE**
  Delivery of physical letters is slow and needless in most cases when locally reproduced facsimile could do.
- **CONCEPT DESCRIPTION**
  Page readers and facsimile printers at each post office read, transmit, receive, and reproduce mail Satellite acts as multi-channel repeater.
- **CHARACTERISTICS**
  - WEIGHT — 20,000 lb
  - SIZE — 200-ft dia antenna
  - RAW POWER — 15 kW
  - ORBIT — Synch. Equat.
  - CONSTELLATION SIZE — 1
  - RISK CATEGORY — I (Low)
  - TIME FRAME — 1990
  - IOC COST (Space only) — 430 M
- **PERFORMANCE**
  Transmits facsimile at 10 pages (8 1/2 x 11") per second per post office. Up to 100,000 post offices serviced in up to 50% of area of U. S. A. Total service = 100 billion pages/day
- **BUILDING BLOCK REQUIREMENTS**
  - TRANSPORTATION — Shuttle and large tug or SEPS
  - ON-ORBIT OPERATIONS — Automated or manual servicing unit; assembly on orbit
  - SUBSYSTEMS — Attitude control; antenna; processor
  - TECHNOLOGY — Large multibeam antenna; multi-channel transponder; LSI processor; multiple-access techniques
  - OTHER — None

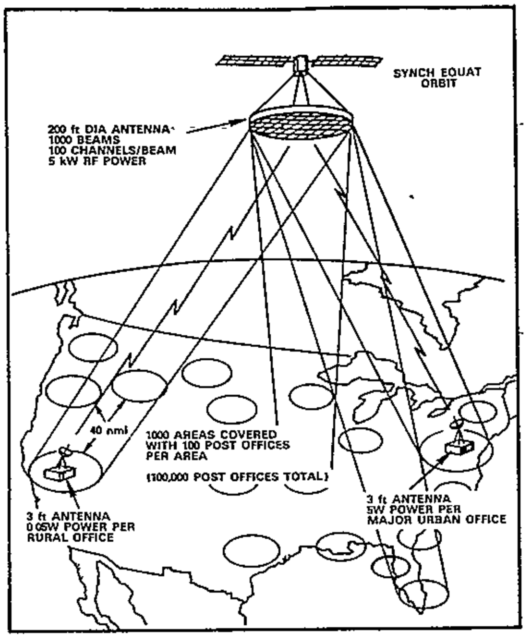


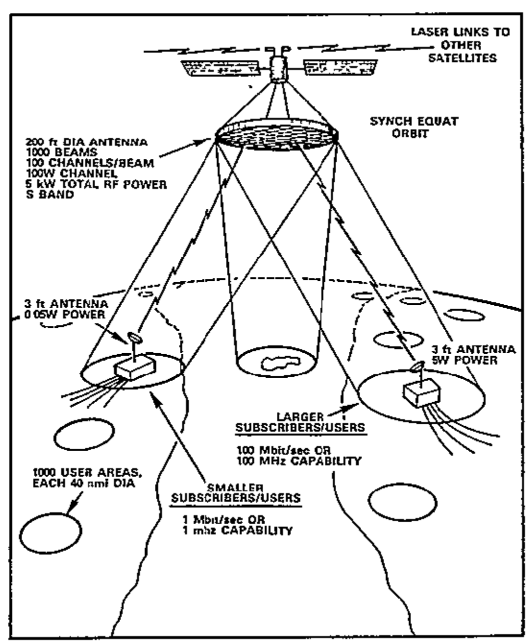
Figure 4-23. Electronic Mail Transmission (CC-4)

could have more capacity than possessed by the entire U.S. mail system today, with essentially instantaneous transmission. Furthermore, because of the ability to serve remote areas, "thin-route" service could be as good as urban service. A single satellite could service 100,000 post offices in up to 50 percent of the total land area of the U.S.A. The privacy of the mail would not be compromised, by making the "reading" and "printing and sealing" machines wholly automatic, and properly coding all the signals. All letters, brochures, newspapers, magazines, bulk mail, etc., could be transmitted in this way. A far-term extension for letters could eliminate the post office intermediate steps by direct transmission from home-to-home, or office-to-office.

The satellite is similar to that in the personal communications, with 1,000 independent beams and 100 channels of reception and transmission for each beam, and would essentially function as a switching and routing center. The size of antenna allows small, low power user (post-office) equipment, so that all post offices can be equipped at a reasonable cost. The satellite weighs about 20,000 lb and requires 15 kW of prime power, but is felt to be a low development risk by the 1990 time period. A shuttle and large tug, or Solar-electric stage would be required to boost it, and for assembly or unfolding and servicing on orbit.

A very similar appearing satellite system could be used for data dissemination within the U.S.A. to small users, or to provide an extension to the international Intelsat system to small users. Domestic or international users could have access to medical or other libraries, and other information banks using only a 3-ft antenna and 0.05 watts of power with a set very much like a citizen's band set, be located anywhere, and receive or transmit up to 1 megabit/second of data. Larger users could use the same size antenna and a 5 watt transmitter to support a data rate up to 100 megabits/sec. Such an initiative, illustrated in Figure 4-24, needs about the same support as does the electronic mail satellite.

- **PURPOSE**
  To provide a National or Intelsat adjunct network with capability to serve small-antenna users.
- **RATIONALE**
  Current satellites require very large antennas and therefore have few entry points - not suited for "disadvantaged" users.
- **CONCEPT DESCRIPTION**
  Large multibeam antenna satellites link facsimile, voice, data, and teletype terminals with low power and small antennas. Satellite is a multi-channel processing repeater.
- **CHARACTERISTICS**
  - **WEIGHT** 20,000 lb
  - **SIZE** 200-ft dia antenna
  - **RAW POWER** 15 kW
  - **ORBIT** Synch. Equat.
  - **CONSTELLATION SIZE** 4
  - **RISK CATEGORY** I (Low)
  - **TIME FRAME** 1990
  - **IOC COST** (Space only) 1.1 B
- **PERFORMANCE**
  400,000 channels of 1 Mbit/sec or 1 MHz capability serviced in 4000 areas worldwide, with 0.05-W transmitters and 3-ft antennas at user terminals.



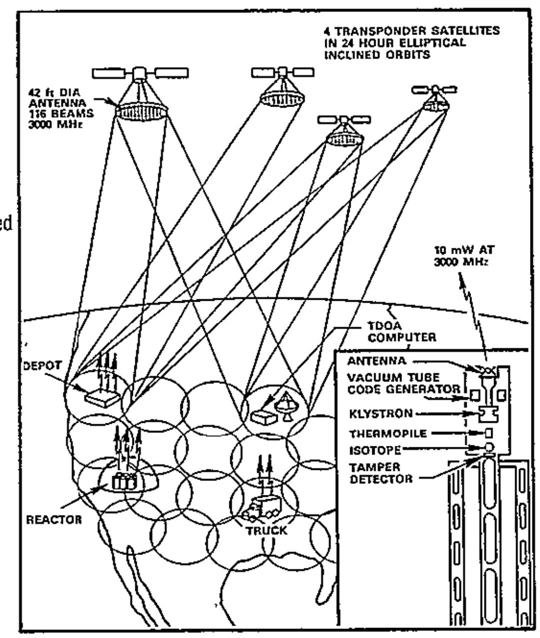
- **BUILDING BLOCK REQUIREMENTS**
  - **TRANSPORTATION** Shuttle and large tug or SEPS
  - **ON-ORBIT OPERATIONS** Automated or manual servicing unit; assembly on orbit
  - **SUBSYSTEMS** Attitude control; antenna; processor
  - **TECHNOLOGY** Large multibeam antenna; multi-channel transponder; LSI processor; multiple-access techniques
  - **OTHER**

Figure 4-24. National Information Services (CC-8)

An application of similar, though smaller satellites addresses an extremely vital problem -- that of aiding in the prevention of diversion or hijacking of nuclear materials used as fuels for nuclear power reactors (as well as other toxic or hazardous materials). In this application, the "tagging" of nuclear reactor fuel element rod assemblies with small radio transmitters, and the subsequent tracking of their signals from space, would enable the hijacking of nuclear materials to be instantly detected, minimizing the danger of nuclear terrorism or blackmail. Though the problems of design of radio transmitters which perform in the heat and radiation environment of the fuel rods are not insignificant, it is likely that ultra-miniature vacuum tubes would perform satisfactorily in such an environment. The concept is illustrated in Figure 4-25.

- **PURPOSE**
  To detect and locate all nuclear reactor fuel elements continuously wherever they are.
- **RATIONALE**
  Real-time monitoring of location of nuclear material needed to prevent proliferation of weapons and nuclear blackmail.
- **CONCEPT DESCRIPTION**
  Each assembly or container is tagged with a microwave generator in a tamper-indicating case. The uniquely coded signals are transponded by four satellites and the position computed by time-difference-of-arrival on the ground.
- **CHARACTERISTICS**

• WEIGHT	3000 lb
• SIZE	42 ft antenna
• RAW POWER	300 W
• ORBIT	Synch. Ellipt./Incl.
• CONSTELLATION SIZE	4
• RISK CATEGORY	1 (Low)
• TIME FRAME	1985
• IOC COST (SPACE ONLY)	270 M



- **PERFORMANCE**
  Each fuel assembly identified and located to ±500 ft continuously, whether in a reactor building, in transit, or in storage; 10,000 assemblies tracked simultaneously.
- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and Tug
• ON-ORBIT OPERATIONS	Automated or manual service unit
• SUBSYSTEMS	Antenna, transponder
• TECHNOLOGY	Multibeam antenna - multi-channel transponder
• OTHER	LSI ground multi-channel cross-correlator receivers; high temperature and high radiation resistant vacuum tube transmitter and code generator; thermopile electrical generator; tamper alarm. Roof transponders.

Figure 4-25. Nuclear Fuel Locator (CO-7)

The "tagging" transmitters would be located and tracked by time-difference of arrival through three or four satellites. The signal can readily pass through the walls of buildings, trucks, factories, etc., either by proper construction or by the provision of suitable transponders. The signals would be "on" at all times from the manufacture of the material, through shipment and use, until destinated or reprocessed. The signals would not be required to transmit through the steel walls of the reactors while operating, however. The satellite system needs only 42-ft diameter antennas with 116 beams, which cover the entire U.S.A. Twenty satellites would be needed to cover the entire world for preventing international blackmail. The satellites are near term, low-risk devices needing but a shuttle and IUS or tug for their orbiting, and automated or manual servicing for their upkeep. There is a great potential payoff in this concept, (combined with security forces), since otherwise nuclear blackmail by terrorist groups will almost certainly become a horrendous problem for which no solution other than administrative controls has been proposed.

The FBI, the CIA, the DoD, the secret service, the treasury department, the border patrol, the national park services, and many other national agencies could very well benefit from the personal navigation, and personal communications functions discussed previously, and illustrated in Figures 4-2, 4-4, and 4-6.

One application of particular relevance to the government is the surveillance of our national borders to prevent the undetected entry of dangerous drugs and illegal aliens. One solution is to place millions of tiny intrusion detection sensors, such as small seismic microphones outfitted with tiny self-contained transmitters, along the entire length of our borders. The sensors could be manufactured to look like small rocks, or plants, or other natural objects, and could be hand emplaced or dispensed from helicopters in rows along the border. A single satellite could detect the signals transmitted by those units sensing footsteps or tire sounds, and would abet the border patrol.

The satellite antenna for such an application is long and thin to generate a footprint roughly coinciding with the shape of the border. In the concept illustrated in Figure 4-26, the antenna measures 1.5 miles by 9 ft

- **PURPOSE**
  To detect overt or covert attempts at crossing a border.
- **RATIONALE**
  Flow of illegal aliens and drug traffickers is a major problem. Detection is difficult along long, unpatrolled borders.
- **CONCEPT DESCRIPTION**
  Very many, very small seismic sensors are read out by a satellite with very large antenna. Penetration causes vibrations which are picked up and correlated at a central site.
- **CHARACTERISTICS**
  - WEIGHT — 8000 lb
  - SIZE — 9000 ft x 9 ft
  - RAW POWER — 20 kW
  - ORBIT — Synch. Equat.
  - CONSTELLATION SIZE — 1
  - RISK CATEGORY — II (Medium)
  - TIME FRAME — 1990
  - IOC COST (Space only) — 170 M
- **PERFORMANCE**
  Virtually all moving objects detected. False alarms sorted by correlation between sensors and fences Sensor life 3.5 years at one penetration attempt per sensor per month.
- **BUILDING BLOCK REQUIREMENTS**
  - TRANSPORTATION — Shuttle and tug
  - ON-ORBIT OPERATIONS — Automated or manual assembly and servicing unit
  - SUBSYSTEMS — Structure; attitude control; antenna
  - TECHNOLOGY — Large passive microwave antenna - stationkeeping subsatellites; laser master measuring and control unit
  - OTHER — Small, light, long-lived sensor units which are very cheap in mass production.

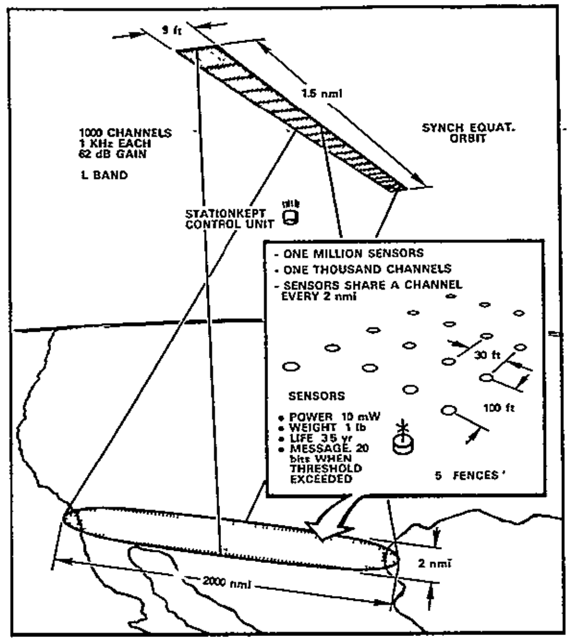


Figure 4-26. Border Surveillance (CO-8)

and generates a beam whose footprint is 2 miles by 2,000 miles. The antenna could be built as a monolithic unit, or more likely consist of a large number of stationkept subelements under position and phase control using a station-kept master unit. One million sensors could easily be monitored, and indeed, one billion could be readily accommodated by proper coding and time/frequency sharing. The large satellite allows the sensors to be tiny (1 lb) and inexpensive, yet long lived (3.5 years average). The satellite volume and weight become equal concerns for the shuttle and tug as supporting elements. Orbital initialization and servicing would be needed, automated or manual. This type of concept is judged to be a medium technological risk due to the large antenna required.

A similar capability to detect intrusions into government buildings and facilities, workhouses, escape attempts from prisons, and generally perform guard duty without requiring expensive labor was illustrated in

Figure 4-8 (burglar alarm and intrusion detection). Such a concept could serve industry, citizens, and government alike, would be a low development risk compared to border patrol, and could become economically justifiable at an early time.

4.1.4.3 Support

The initiatives described in this portion are those whose function primarily supports surface activities other than direct communications or observation. Included are functions such as energy delivery and distribution, mass delivery, and several miscellaneous.

The first initiative has as its intent to make radar inexpensive and widely available to pleasure craft and other surface vessels operating in the coastal areas, for the purposes of radio location and collision avoidance. In order to do this, a bistatic radar technique is envisioned using a large space array to illuminate the coastal regions with radio energy, which is reflected from objects on the surface and received by passive receivers with scanning antennas on the pleasure craft or other users. In this way, minimum spectrum congestion and minimum expense would result, the benefits of radar can be made available to millions of users at a much lower cost (the radar transmitter and modulator are the most expensive parts of a set) and with no spectrum congestion and interference (hundreds or thousands of radars operating in the same area would inevitably cause great interference with each other or use up a huge spectrum). The initiative is illustrated in Figure 4-27. The mechanization of the technique involves scanning a 2,000 mile long coastline out to 200 nmi by two high power transmitter satellites in synchronous equatorial orbit. The vessels are equipped with fairly conventional radar receivers and scanning antennas where the antennas provide azimuth indication and a range-gated display provides range indication. Unlimited number of users can simultaneously utilize the signals generated by the space illuminators, and obtain radar with 12 nmi range. The size and power of the space transmitter is given more by the clutter which has to be rejected, rather than by the location accuracy desired.

- **PURPOSE**
  Inexpensive and lightweight radar for all surface vessels - navigation; collision avoidance.
- **RATIONALE**
  Conventional radar too expensive and interference prone. Pleasure craft usually denied radar benefits.
- **CONCEPT DESCRIPTION**
  Illuminate seacoasts with scanning microwave beams from space. Scanning receiving antennas on boats obtain range and angle data on hazards.
- **CHARACTERISTICS**

• WEIGHT	2,000,000 lb
• SIZE	1,000 x 10,000 ft
• RAW POWER	3 MW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	2
• RISK CATEGORY	II (Medium)
• TIME FRAME	1995
• IOC COST	10 B

- **PERFORMANCE**
  Relative location of all objects >100 m^2 within 12 nmi range. 100 x 300 ft accuracy in 50° sector. 3 x 0.5 ft antenna in vessel. Unlimited number of users.
- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	LLV and large tug or large SEPS
• ON-ORBIT OPERATIONS	Automated or manual servicing unit; assembly in orbit
• SUBSYSTEMS	Structures; attitude control; antenna; power
• TECHNOLOGY	Large adaptive microwave antenna; high power transmitters; prime power source.
• OTHER	

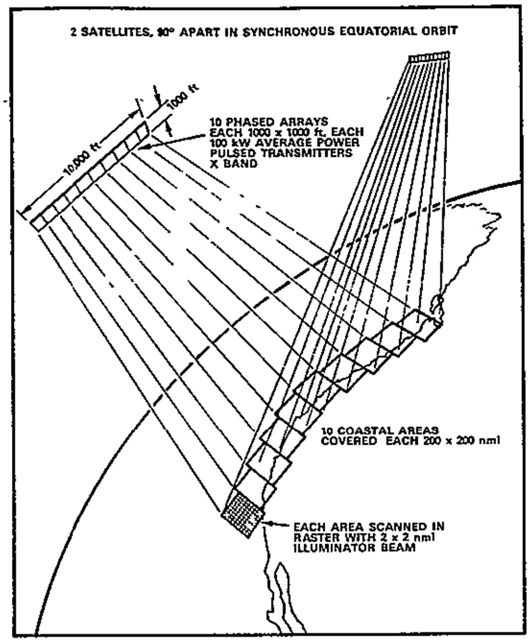


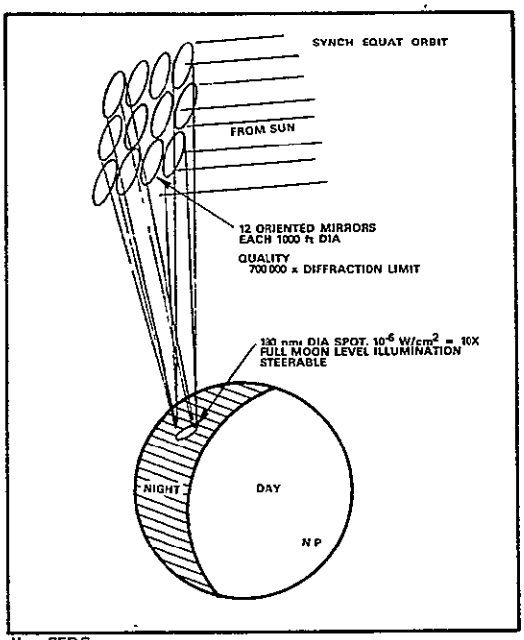
Figure 4-27. Coastal Anti-Collision Passive Radar (CO-9)

This is another example in which simplicity and economy can be gained for a very large number of users at the expense of size and complexity in the spacecraft, since the user equipment should cost only a fraction of that for a current shipboard radar for pleasure craft.

The large and heavy phased array antenna will be assembled in orbit and will require orbital servicing. The shuttle will be satisfactory as a booster, but a large tug and/or Solar-electric stage will be needed for orbit transfer. The system concept is Category II medium risk.

A number of concepts for delivery of energy from space have been identified. The first concept delivers energy in the form of attenuated sunlight for illumination of cities or highways at night. The initiative is illustrated in Figure 4-28, and is seen to consist of large, plane reflectors which reflect a 180 nmi diameter image of the sun onto the earth from synchronous orbit. The image brightness depends on the area of the reflectors,

- **PURPOSE**
  To provide night lighting without earth-based energy, pollution, street lights, cables, trenches, etc
- **RATIONALE**
  Alternative energy sources are needed.
- **CONCEPT DESCRIPTION**
  Large area reflectors in space reflect the image of the sun onto the earth. Multiple satellites used to minimize construction difficulties.
- **CHARACTERISTICS**
  - WEIGHT: 100,000 lb
  - SIZE: 12 mirrors each 1,000-ft dia
  - RAW POWER: 1.2 kW
  - ORBIT: Synch. Equat.
  - CONSTELLATION SIZE: 1
  - RISK CATEGORY: II (Medium)
  - TIME FRAME: 1990
  - IOC COST (Space only): 160 M
- **PERFORMANCE**
  Ten times full-moon level illumination at night provided to area 180 nmi dia (no clouds). Full moon level provided through moderate clouds.



- **BUILDING BLOCK REQUIREMENTS**
  - TRANSPORTATION: Shuttle and large tug and/or SEPS
  - ON-ORBIT OPERATIONS: Automated or manual servicing unit
  - SUBSYSTEMS: Attitude control; mirrors, structure
  - TECHNOLOGY: Large reflector; pointing; stationkeeping master control
  - OTHER: None

Figure 4-28. Night Illuminator (CS-6)

and for the 12 mirrors, each 1,000-ft diameter, a brightness equivalent to 10 times full moonlight is delivered on a cloudless night. That is about the same as the illumination standards in residential areas in between light poles. The presence of even dense cloud cover will not reduce the brightness below equivalent full moon due to multiple scatter. The large area covered is evenly illuminated.

The mirrors can be very coarse by optical standards, since the beam spread can be as much as 0.1 degrees. The satellites are seen as three-axis stabilized tensioned sheets of aluminized mylar or similar thin film. The satellite total weight is about 150,000 lb, which would require the shuttle, large tug, and/or Solar-electric stage. The satellite is categorized as medium risk due to the size of reflector involved, requiring demonstration even though no great technological problems are expected.

Other uses for this initiative would be the provision of emergency illumination to disaster areas or areas hit by power blackouts.

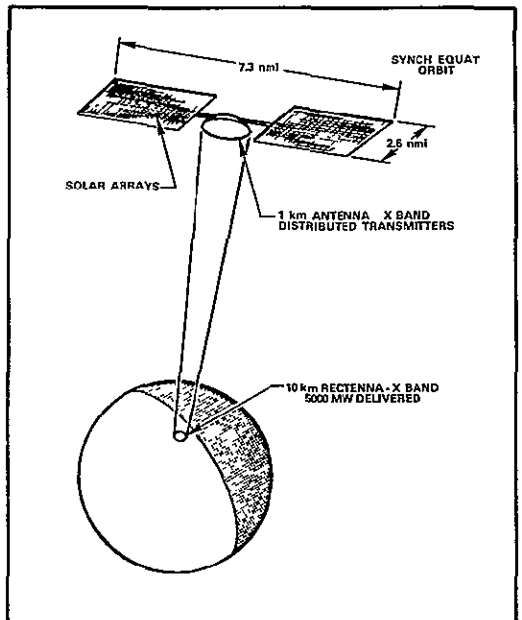
Some of the most intriguing applications deal with energy generation and delivery, increasing the supply of a scarce resource while minimizing environmental impact. The first initiative intercepts large amounts of solar energy, transforms it into microwave energy, and beams it to the ground where it is captured by a large receiving array and carried away on transmission lines. The initiative illustrated in Figure 4-29 is identical to the Satellite Solar Power Station design proposed by Glaser (A. D. Little) et. al. It utilizes a 1 km diameter microwave antenna to focus the beam to the 10 km diameter of the receiver. The satellite utilizes solar cells with 2/1 concentrating mirror surfaces and attains about 13 percent conversion efficiency to DC in the satellite, with about 60 percent DC to DC transmission efficiency, or an overall efficiency of about 6.6 percent. The satellite is sized to provide 5,000 megawatts of electrical power, weighs about 40,000,000 lb in synchronous orbit, and extends about 7.3 x 2.6 nmi. The support requirements include a large lift vehicle (larger than the shuttle by a factor of 5-10), a large tug, and/or a Solar-electric stage. Manned assembly in orbit and manned servicing would be a must with this system. The large microwave antenna, the solar array, or both could be fabricated as monolithic structures or consist of loosely stationkept elements forming controlled dense arrays. The receiving array consists of a 10 km array of wires and rectifiers which could be suspended on poles and allow farming underneath. This concept is a high risk, long-term undertaking of very large proportions. The peak energy density on the center of the microwave beam is about 20 mW/cm^2.

A new idea for a technique of significantly increasing the solar energy collection efficiency and reducing the costs has been conceived at Aerospace, and it is incorporated into the above solar power satellite concept. The results are illustrated in Figure 4-30. The basic technique involves the

- **PURPOSE**
  To provide abundant electrical power with little pollution.
- **RATIONALE**
  More and clean energy needed.
- **CONCEPT DESCRIPTION**
  Solar energy is collected, converted to microwave energy, and transmitted to earth, where it is rectified to DC by a rectenna.
- **CHARACTERISTICS**

• WEIGHT	40,000,000 lb
• SIZE	7.3 x 2.6 nmi
• RAW POWER	10,000 MW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	IV (High)
• TIME FRAME	2000
• IOC COST (Space only)	61 B

- **PERFORMANCE**
  5,000 megawatts supplied to 10 km collector, with less than 500 MW lost as heat to the environment, at a cost of ≈ $1,500 per kW.



- **BUILDING BLOCK REQUIREMENTS**

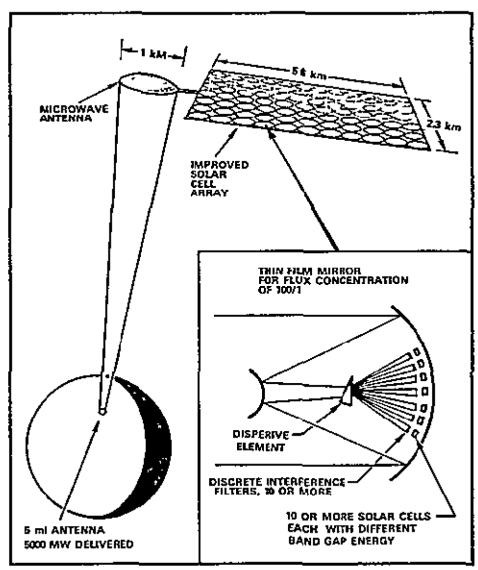
• TRANSPORTATION	LLV and large tug and large SEPS
• ON-ORBIT OPERATIONS	Manned servicing unit; assemble in orbit
• SUBSYSTEMS	Attitude control; structures, power antenna
• TECHNOLOGY	Large economical solar arrays; large active microwave antenna; high power tubes; feeding and cross-connects
• OTHER	Rectenna on ground

Figure 4-29. Energy Generation - Solar/Microwave (CS-1)

- **PURPOSE**
  To increase the efficiency and decrease the cost of solar power delivery from space
- **RATIONALE**
  Solar power satellites will be large, heavy, and expensive.
- **CONCEPT DESCRIPTION**
  Efficiency and cost of solar-voltaic conversion can be greatly increased by using multiple cells, each tailored to the photon energy in a restricted spectrum; and by using high ratio solar flux concentration.
- **CHARACTERISTICS**

• WEIGHT	8,000,000 lb
• SIZE	5.6 x 2.3 km
• RAW POWER	10,000 MW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	IV (High)
• TIME FRAME	2000
• IOC COST	TBD

- **PERFORMANCE**
  Same power delivered with one fifth the weight in orbit compared to the current solar power satellite concept (CS-1) and probable but undetermined cost reduction.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	LLV and large tug and large SEPS
• ON-ORBIT OPERATIONS	Manned servicing unit; assemble in orbit
• SUBSYSTEMS	Attitude control; structures; power antenna
• TECHNOLOGY	Large economical solar arrays; large active microwave antenna; high power tubes; lightweight concentrator; thermal design
• OTHER	Rectenna on ground

Figure 4-30. High Efficiency Solar Energy Generation (CS-2)

use of several solar cell types, each designed for a different band gap energy, and each preceeded by a filter to let through only a limited range of wavelengths around the peak of efficiency of the solar cell which it feeds. In addition, a large concentration ratio (about 100/1) mirror would be used with each group of cells, minimizing the area of expensive solar cells per unit of energy collected by the mirror. Further, the design of the cells would use one extremely thin insulating layer such that the temperature rise of the cell could be limited by conductive heat transfer to the mounting substrate, which could be the mirror itself. The combination of the three principles: (solar cells with tailored band gaps, high flux concentration ratios, and highly thermally conductive solar cell designs) should allow ultimate increases of efficiency approaching 80 percent for the system, and a weight saving resulting in 20 percent system weight compared to the design in Figure 4-29. A cost saving is expected, since the total area of solar cells is decreased from about 26 km^2 to 0.1 km^2, a factor of 260. even though concentrator mirrors and interference filters are added, they probably will not be as expensive as solar cells.

The technology of such highly efficient solar converters certainly will be applicable to lower power supplies for other satellites as well.

A different version of energy delivery is illustrated in Figure 4-31 in which a breeder nuclear reactor powers an MHD generator to produce electricity which is beamed to earth via a microwave antenna identical to that in Figure 4-29. There are no outages with this system during periods of eclipse, but the nuclear wastes must be disposed of periodically by accelerating them to escape velocity, or stored in orbit and carefully monitored. Other versions of power generators are also possible including a solar collector heating a Brayton cycle machine operating an electrical generator. All of these systems avoid excessive heating and particulate pollution on earth. Trade studies on the most desirable ones are on-going.

An intriguing possibility for energy distribution is using microwave beams reflected from satellites to replace or augment terrestrial

- **PURPOSE**

  To generate and deliver electrical energy without pollution or hazard.

- **RATIONALE**

  Power is needed which requires no radioactive material on earth, produces no atmospheric heating, and no resource consumption.

- **CONCEPT DESCRIPTION**

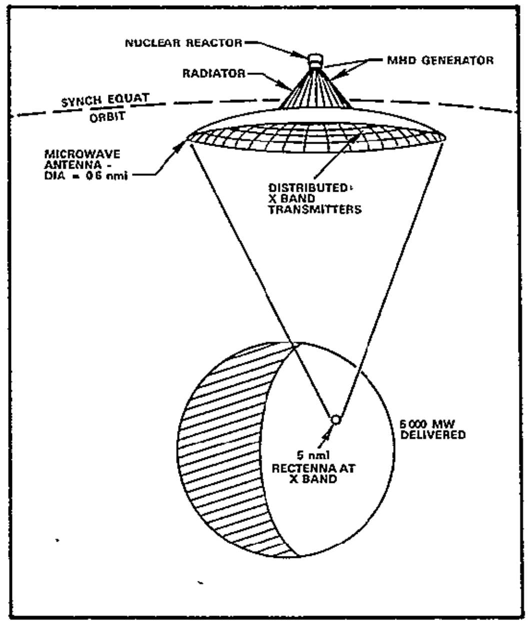
  A breeder reactor, MHD power generator, microwave transmitter, and microwave antenna are used to beam energy to a ground receiver. Fuel breeding supplies fuel.

- **CHARACTERISTICS**

• WEIGHT	TBD
• SIZE	3,600-ft dia
• RAW POWER	10,000 MW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	IV (High)
• TIME FRAME	2000
• IOC COST (Space only)	TBD

- **PERFORMANCE**

  5,000 Megawatts delivered power continuously - with sufficient fuel breeding for a life of at least 1000 years.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	LLV and large tug and large SEPS
• ON-ORBIT OPERATIONS	Manned service unit, automated servicing unit; assemble in orbit
• SUBSYSTEMS	Structure; attitude control; antenna; reactor; power unit
• TECHNOLOGY	Large active microwave antenna; large reactor; heat radiator; MHD power generator; pointing and tracking sensor
• OTHER	Rectenna on ground, safety

Figure 4-31. Energy Generation - Nuclear/Microwave (CS-3)

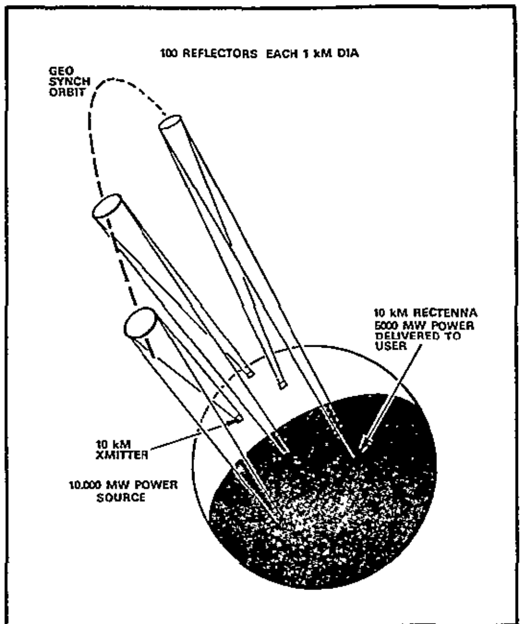
power transmission lines. Two versions are conceptualized, one which is suitable for very long range, point-to-point transmission distances of bulk energy, and the other designed for shorter range but more flexible service to substation-sized terminals.

The first concept similar to one proposed by Dr. Krafft Ehricke, uses 1 km reflectors in synchronous equatorial orbit to reflect 10,000 megawatts of power from a 10 km diameter source antenna to a 10 km diameter receiving array. This concept, illustrated in Figure 4-32, is ideally suited for transmission of huge amounts of power from sunlight-rich regions of the earth to other regions, and from the sunlit side of the globe to the night side. The concept illustrated consists of enough reflectors, transmitters, and rectennas to supply about 10 percent of the U.S. consumption of electrical energy, though smaller or larger numbers are just as valid.

- **PURPOSE**
  To provide for transmission of electrical power from remote regions, minimizing environmental impact.
- **RATIONALE**
  Power should be generated in remote regions.
  Sunny side of Earth can supply power to night side.
- **CONCEPT DESCRIPTION**
  Source power is converted to a microwave beam, bounced off an orbiting reflector, and reconverted to DC at receiving antenna on ground.
- **CHARACTERISTICS**

• WEIGHT	600,000 lb
• SIZE	0.5-nmi dia
• RAW POWER	---
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	100
• RISK CATEGORY	IV (High)
• TIME FRAME	1995
• IOC COST (Space only)	36 B

- **PERFORMANCE**
  5,000 megawatts delivered to each of 100 user areas. 53 percent overall DC-DC efficiency attained. Total energy is about 10 percent of U. S. consumption.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	LLV and large tug or large SEPS
• ON-ORBIT OPERATIONS	Manned/automated servicing, assemble in orbit
• SUBSYSTEMS	Attitude control; structures, phase front control
• TECHNOLOGY	High efficiency, large, passive steerable phase front antenna; Ion thrusters
• OTHER	Ground-based elements

Figure 4-32. Power Relay Satellite (CS-15)

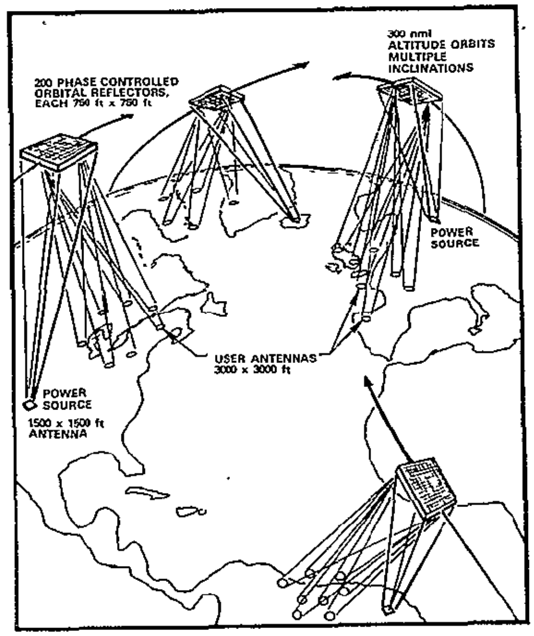
The reflector satellite is assumed to be a monolithic flat structure, passive except for figure control, attitude control, and stationkeeping. The weight of each reflector is about 600,000 lb, and a large launch vehicle, large tug, and/or large Solar-electric stage are required for launch support, as are orbital assembly and servicing. This concept is also Category IV high risk due to the size of the structure. The monolithic structure proposed by Dr. Ehricke could be replaced with a stationkept array of smaller structures, each phase/delay controlled. This might result in weight savings, or more likely, in more readily attained "planar" configuration and lower losses.

The second concept for distribution of energy is oriented to provide power at the local substation level (100 MW). This concept was conceived during the study to reduce needs for new long-range transmission lines on a global basis, while concentrating the power generators in relative unpopulated regions. The concept, illustrated in Figure 4-33, aims to relay

- **PURPOSE**
  To distribute energy to small-city users without transmission lines, and serve many nations simultaneously.
- **RATIONALE**
  Transmission lines are fixed, have an environmental impact, and limited capacity to feed growing communities or developing nations without large networks or large losses
- **CONCEPT DESCRIPTION**
  Phase-controlled array reflectors in low orbit sequentially relay remote source power to 100 user antennas per satellite. Power is rectified at substation receiving arrays and filtered.
- **CHARACTERISTICS**

• WEIGHT	34,000 lb
• SIZE	750 x 750 ft
• RAW POWER	20 kW
• ORBIT	300 nmi several incl.
• CONSTELLATION SIZE	200
• RISK CATEGORY	IV (High)
• TIME FRAME	2000
• IOC COST (Space only)	5.8 B

- **PERFORMANCE**
  1000 user areas in U. S. A. powered with 100 MW each in rapid (1/120 sec) sequence from 10 power station source antennas. Scanning loss < 1%; overall efficiency >55% 3000-ft square receiver with 1.7 nmi square guard fence suffices for user.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle
• ON-ORBIT OPERATIONS	Shuttle attached manipulator; manual or automated servicing unit
• SUBSYSTEMS	Attitude control, stationkeeping units, phase control, figure control
• TECHNOLOGY	Ion thrusters, phase control, measurement and control lidar, LSI processor
• OTHER	

Figure 4-33. Multinational Energy Distribution (CS-8)

ground-generated energy using low altitude space reflectors, each supplying a number of substation user areas, obtaining a flexibility of power interconnect without wires approaching that of radio communications. Power could be supplied to growing or new communities within the U.S. from source areas in remote U.S. regions. The same satellites, being in low orbit, could be used by other nations as the basis of their distribution nets as well, with no interference in U.S. distribution. Developing nations could depend entirely on space relay of power, instead of terrestrial distribution. The concept illustrated employs phase-controlled microwave reflectors in low orbit in which the angle (in two dimensions) of reflection of the source beam is controlled and varied so as to point the beam at many user rectennas in rapid sequence. The rapidly pulsating power is filtered by active or passive techniques at each substation. Power programming can be accomplished by changing the duration of the illumination cycle to the user antennas.

C-2

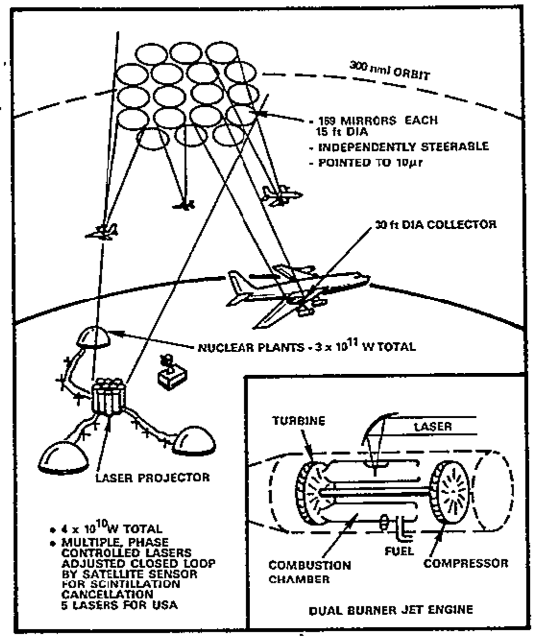
The concept allows 10 source area transmitters within the U.S. to feed 100 megawatts to each of 1,000 user area receivers, each 3,000-ft square by reflecting off several of 200 reflector satellites in low orbit. The power is received at the user areas as 7×10^{-3} sec long pulses, at the rate of 120-150 pulses per second. RLC or synchronous filters can be used to filter the pulsating power. The average energy density of the center of the beam at a user antenna is 7.6×10^{-3} W/cm^2, less than that of the solar power satellite of Figure 4-29. A two-mile fence surrounding the receiver will assure that transient power levels are less than 10^{-4} W/cm^2 - a sure safe level. Beam pointing would be by active retrodirection of pilot signals generated at the user areas.

The satellites are seen as 34,000 lb monolithic or stationkept arrays measuring 750 x 750 ft, under active phase delay control for reflection angle steering. Though this is a high risk initiative for the year 2000, only the space shuttle is needed for boost, assembly, and servicing.

Ultimately in the very far future, the power could be generated in space and delivered to the users directly, utilizing fewer but larger phase-controlled antennas at higher altitude.

Large commercial jet aircraft use about 10 percent of the total transportation energy consumed in the U.S. A number of schemes are possible for reducing or eliminating the dependence of such aircraft on the continued availability of petroleum fuel. One such possibility utilizes space to provide the power needed for flight, and is illustrated in Figure 4-34. Laser energy is generated on the ground and is beamed via space satellite mirrors to aircraft in flight. This laser would be powered by nuclear power plants on the ground in the "nearer term," but eventually could be space based and powered by nuclear or solar energy. The laser energy is beamed to the engines via a collector on the upper surface of the aircraft. The engines are somewhat similar in principle to conventional jet engines, but instead of energy being supplied to the inlet air by the combustion of jet fuel, the energy is supplied by the absorption of the laser beam which would

- **PURPOSE**
  To provide an alternative to oil as a source of energy for powering commercial transports.
- **RATIONALE**
  Oil is a limited resource, becoming more expensive rapidly.
- **CONCEPT DESCRIPTION**
  Jet turbines are operated by heating air with laser beams projected to each aircraft by multi-mirror satellites. Laser on ground powered by nuclear reactors provides energy.
- **CHARACTERISTICS**
  - WEIGHT — 2,000,000 lb
  - SIZE — 169 mirrors, each 15-ft dia
  - RAW POWER — ---
  - ORBIT — 300 nmi, 45^0 incl.
  - CONSTELLATION SIZE — 200
  - RISK CATEGORY — IV (High)
  - TIME FRAME — 2000+
  - IOC COST (Space only) — 87 B
- **PERFORMANCE**
  2000 large jet aircraft powered continuously (30% duty cycle) at 10-50 MW/aircraft. Break-even with oil operations at 50¢/gal.



- **BUILDING BLOCK REQUIREMENTS**
  - TRANSPORTATION — LLV and large SEPS
  - ON-ORBIT OPERATIONS — Manned or automated servicing unit; orbital assembly
  - SUBSYSTEMS — Attitude control; mirrors; processors; crosslink; thermal control
  - TECHNOLOGY — Large high temp mirrors; radiators; pointing and tracking sensors; LSI processor
  - OTHER — Ground high energy laser; atmospheric scintillation correction. Safety

Figure 4-34. Aircraft Laser Beam Powering (CS-5)

be focused into a very small volume within a "combustion chamber." The heated air drives the turbine/compressor as well as the aircraft. In this application, some jet fuel must be carried by the aircraft for conditions where the aircraft is under cloud cover thick enough that the laser will not penetrate, typically in some takeoff and landing situations. A number of ground laser stations is required, both for geometrical coverage and to assure cloud-free paths to space a large fraction of the time. Should the lasers be space-based, part of the problem is reduced. The power delivered to each aircraft is 10-50 megawatts, and the system is sized to power a year 2000 fleet of 2,000 large transports at one-third duty cycle. In principle, most of the current fuel load can be converted to payload, and arbitrarily long flight time attained.

The total electrical energy required to power the lasers is a significant fraction of that which supplies the entire electrical needs of the United States today.

The space mirror complex may be viewed as an energy common carrier, with the energy supplied either from the ground or from space, manipulated and directed in space. The generation and transmission via laser beams of the huge quantities of energy which are assumed in this concept greatly outstrips the capabilities of today's technology; however in principle, the laser techniques required are known. The satellites are 200 clusters of 169 mirrors - each 15-ft diameter, capable of diffraction - limited performance under high transient heat loads. Each of the 11,000 lb mirrors is three-axis controlled and stationkept.

The large and complex satellites would almost surely require manned assembly, initialization, and servicing, and space transportation systems of greater payload weight and volume capacity than the Space Shuttle and tug. The concept is high risk, not only because of the technology required, but because of the potential danger to the surface if the laser beam wanders off the aircraft collector as a result of failures in the automatic tracking and safety override systems.

Not all initiative concepts need be as grandiose as those which are tasked with delivering or distributing energy, and yet make contributions to the energy field. The initiative concept was illustrated in Figure 4-10. Its intent is to monitor the power flow (voltage, current, power, power factor, etc.) at a very large number of points in the power distribution grid, to allow fine-scale yet extremely broad power programming, power sharing, consumption monitoring or regulation, or other allied functions.

The wholesale use of nuclear reactors will surely create a hazard problem for disposal of the highly radioactive waste by-products of operation. Deep space could advantageously be used for disposal of such hazardous materials, which would be boosted to escape the solar system, or impact the moon, fall into the sun, and never return to earth. This form of disposal, illustrated in Figure 4-35, could be far safer than any involving long-term

• PURPOSE

To permanently dispose of nuclear wastes without environmental damage.

• RATIONALE

Wholesale use of nuclear generating plants for electric power will result in large amounts of highly toxic and long lived radioactive wastes.

• CONCEPT DESCRIPTION

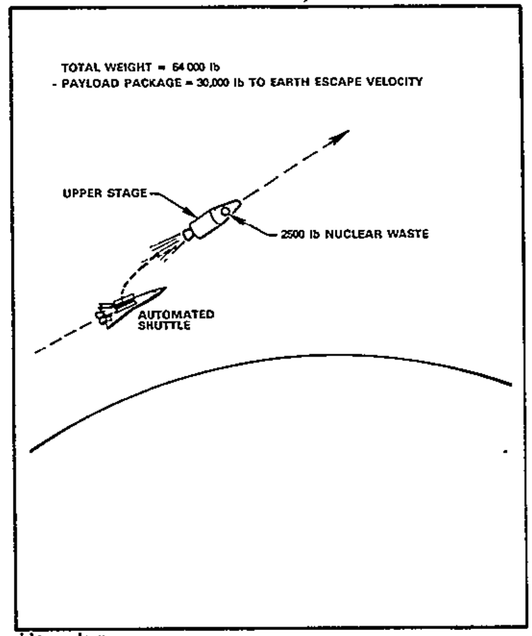
Wastes are packaged in containers with shielding and cooling, and put into earth escape trajectories by shuttle and velocity stages.

• CHARACTERISTICS

• WEIGHT	64,000 lb
• SIZE	15 x 60 ft
• RAW POWER	---
• ORBIT	Escape
• CONSTELLATION SIZE	---
• RISK CATEGORY	II (Medium)
• TIME FRAME	1990 - 2000
• IOC COST (SPACE ONLY)	430 M

• PERFORMANCE

2500 lb of waste per flight at $15 million per flight ($6000/lb). Cost increase to electrical consumer = 2%.



• BUILDING BLOCK REQUIREMENTS

• TRANSPORTATION	Automated shuttle and large tug
• ON-ORBIT OPERATIONS	Safety/abort - backup systems
• SUBSYSTEMS	Shielding/encapsulation; abort systems
• TECHNOLOGY	Thermal control; structural package integrity; recovery techniques
• OTHER	

Figure 4-35. Nuclear Waste Disposal (CS-4)

storage of such material on the earth. The principal problem would be packaging the waste in containers that would resist rupture even in explosions on the launching pad, aborts from sub-orbital trajectories, sinking to the ocean depths, or burial underground after reentry. An unmanned shuttle-like launch vehicle and tug would probably be required for such continuing operations. There exists the possibility of accumulating the nuclear wastes in orbital way-stations, and then accelerating them using a thermo-electric-ion transfer stage, possibly accruing some savings.

The scale of space operations implicit in many of the initiatives described in this study is such that space will be populated by vast quantities of "junk" representing a threat to further space operations. An initiative designed to remove this "space pollution" is described in Figure 4-36. The intent of this initiative is to remove spent stages, satellites no longer

- **PURPOSE**
  To remove expended satellites and debris from synchronous equatorial corridor where they pose a long-term collision threat.
- **RATIONALE**
  Synchronous equatorial corridor is becoming very crowded and could be dangerous in future.
- **CONCEPT DESCRIPTION**
  Use tug to impart ΔV to debris to drop its perigee to < 100 nmi. Debris will reenter within weeks. One orbit later, tug re-injects itself into SE orbit. Tug resupplied by shuttle.
- **CHARACTERISTICS**

• WEIGHT	500,000-lb propellant
• SIZE	Tug
• RAW POWER	--
• ORBIT	Up to Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	1 (Low)
• TIME FRAME	1985
• IOC COST (Space only)	0.5 M

- **PERFORMANCE**
  500,000 lb of propellant will deorbit 100 satellites of 5,000 lb each.

- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and tug
• ON-ORBIT OPERATIONS	No unusual requirements
• SUBSYSTEMS	No unusual requirements
• TECHNOLOGY	No unusual requirements
• OTHER	None

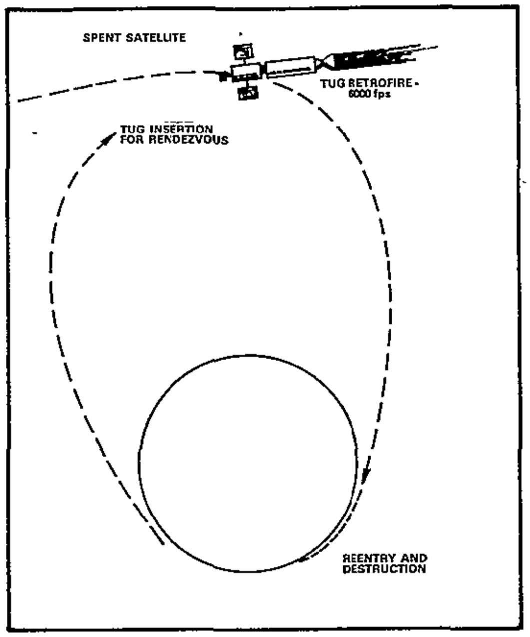


Figure 4-36. Space Debris Sweeper (CS-11)

considered useful, pieces of debris such as bolts, bands, shields, fairings, etc., from near-earth space in order to reduce the danger of collisions. Such dangers will increase with time and increasing space use. The initiative dedicates a tug permanently stationed in orbit. The tug performs a rendezvous with the spent satellite or debris and applies a retrofire burn to drop the perigee of the debris to 100 nmi or less, such that its orbit will decay and the object will reenter within some reasonable time, such as a few weeks. An alternate technique is to add velocity so the object escapes. The latter may well minimize propellant expenditures for high altitude junk. The shuttle is used to resupply propellants to the tug so that it may perform multiple deorbit burns, reinject itself into stable orbits, and perform the required rendezvous with space junk. A permanently orbiting Solar-electric stage would even be more advantageous than the tug. In the far term, the junk collected would be reprocessed in orbital factories to build components for further space operations.

- **PURPOSE**
  To reduce the depletion of the ozone layer from "freon" compounds.

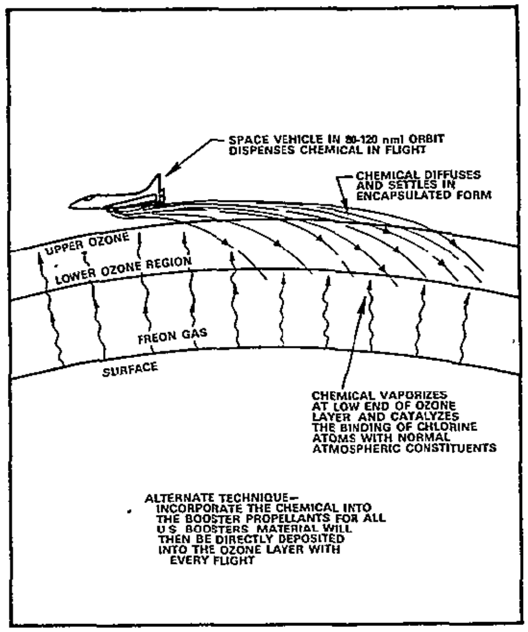
- **RATIONALE**
  The ozone concentration in the layer is decreasing dangerously due to freons released by spray cans and refrigerators.

- **CONCEPT DESCRIPTION**
  Space shuttle or heavy lift booster dispenses a chemical which settles and catalyzes the binding of free chlorine atoms produced by the freon, preventing the chlorine from destroying ozone.

- **CHARACTERISTICS**

• WEIGHT	50,000,000 lb
• SIZE	---
• RAW POWER	---
• ORBIT	80-120 nmi polar
• CONSTELLATION SIZE	1
• RISK CATEGORY	IV (High)
• TIME FRAME	1995
• IOC COST (Space only)	750 M

- **PERFORMANCE**
  Ozone layer replenished, protected for five years by dispensing of 25,000 tons of chemical in the northern hemisphere.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	LLV
• ON-ORBIT OPERATIONS	No unusual requirements
• SUBSYSTEMS	Reentry package for dispensing at the proper altitude
• TECHNOLOGY	No unusual requirements
• OTHER	Phenomenology of ozone layer depletion; synthesis of solely-chlorine-active catalyst. Environment side-effects.

Figure 4-37. Ozone Layer Replenishment/Protection (CS-12)

Finally, a much less well defined initiative, but whose value could be immensely greater is illustrated in Figure 4-37. This initiative addresses the potential problem of depletion of the earth's ozone layer, with the consequent increase of ultra-violet radiation on the surface resulting in varied harmful biological effects. Even though the phenomenology is not yet completely understood, it appears that freon gases liberated from aerosol spray cans, as well as oxides of nitrogen generated by very high altitude aircraft can cause the ozone concentration to fall over a period of many years by a very complex chain interaction in the upper atmosphere. In this initiative an encapsulated chemical, yet to be synthesized, would be dispensed from a low flying satellite or space shuttle to settle and disperse in the ozone region. The encapsulation would be designed so as to evaporate near the lower end of the ozone region releasing the chemical.

The characteristics desired for this special chemical would be: it should have a high affinity for the chlorine radical released by freon photolysis and a low affinity for oxygen, ozone, and the other components in the equilibrium reactions in the region; it would have to have a low potential for dissociation under sunlight; and it would have to be stable over periods measured in years.

This chemical would bind to the chlorine radicals and then catalyze the interaction of cl with normal atmospheric cleanup components such as HNO_3 or CH_4, thus breaking the ozone destruction chain reaction. A single application of the chemical would last for many years due to the low vertical diffusion rates at the altitudes of the layer. The quantity required could be fairly small. The phenomenology of the ozone layer formation and its depletion are under active study currently. Synthesis of the freon-radical consuming catalyst necessary for this initiative is speculative at this time. However, the possibility exists that this very important world problem could be amenable to solution from space. The solution to the oxides of nitrogen from aircraft would seem to be in controls at the source.

4.1.5 International Applications

A number of satellite concepts are particularly well suited for multinational applications which would encourage peaceful cooperation, and aid in establishing economic ties with other nations. The initiatives discussed in this category are:

1. Diplomatic/U.N. "Hot Lines"
2. National Information Services
3. Multinational Air Traffic Control Radar
4. Multinational Energy Distribution
5. Earth Resources/Pollution Data Sharing
6. U.N. Truce Observation Satellite

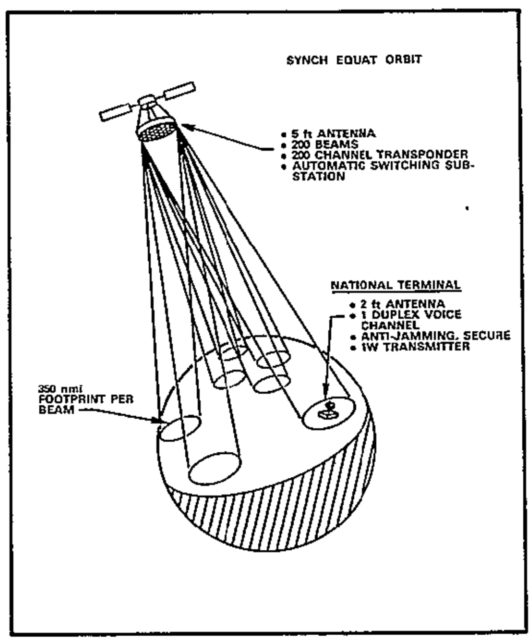
Some of these are initiatives previously described under other categories but having clear potential for international applications.

The first such application utilizes multibeam antenna communication satellites similar to those first described in personal communication initiatives, but is intended rather to provide "hot-line" communications between heads of state of all major nations of the world, between diplomatic embassies, or both in order to provide a medium for easing tensions, negotiating differences, and reducing the danger of escalation of minor conflicts into major ones. The concept is illustrated in Figure 4-38, and features the use of small, inexpensive, and portable national terminals to make the network readily accessible to all nations.

- **PURPOSE**
  To provide rapid, reliable, secure communications between heads of state (or embassies).
- **RATIONALE**
  Good, rapid communications needed to reduce dangers of escalation in international situations.
- **CONCEPT DESCRIPTION**
  Multibeam antenna Comsat crosslinks any or all terminals, one per country. Satellite processing is autonomous and not subject to capture.
- **CHARACTERISTICS**

• WEIGHT	3000 lb
• SIZE	5 x 20 ft
• RAW POWER	1 kW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	3
• RISK CATEGORY	1 (Low)
• TIME FRAME	1985
• IOC COST (Space only)	330 M

- **PERFORMANCE**
  One full duplex voice channel per country, secure, 200 countries accommodated. Automatic switching in satellite; or multiple access user-controlled.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle and IUS/tug
• ON-ORBIT OPERATIONS	Automated or manual servicing unit
• SUBSYSTEMS	Attitude control; antenna; processor and switch
• TECHNOLOGY	Multibeam antenna; multi-channel transponder; LSI processor and automatic switch; multiple-access techniques
• OTHER	None

Figure 4-38. Diplomatic/U.N. Hot Lines (CC-10)

The dedicated nature of the satellite and its mutual need by all nations makes it an unlikely target. The satellite has a 4-ft antenna but is powerful enough that a 2-ft user antenna terminal is sufficient to support a duplex voice channel with anti-jam coding, which is automatically switched in the satellite to whichever country addressee the call initiator specifies. Thus, any country can be in touch with any other country at will, not subject to the whims of any other country. With the automatic switching equipment being satellite-borne and pre-programmed, fairness of access is insured to all and is not subject to capture or control by any party who may be interested in upsetting communications. The satellite antenna is state of the art, although the automatic switching substation requires development of an appropriate LSI processor and multiple access techniques. This concept is a low risk development requiring only a shuttle and IUS/tug for its launch and support.

A refinement of this concept is to combine it with the 3-D holographic teleconferencing of Figure 4-13 so that heads of state cannot only talk to each other, but meet "face-to-face" whenever needed. Such "instant summits" could very well revolutionize international diplomacy.

An application of the initiative illustrated previously in Figure 4-24 and entitled "National Information Services" would enable expansion of the Intelsat network to provide service to small commercial or national users, or could form the backbone of a library and data-sharing service among many nations without tying up the Intelsat common-user circuits. The important feature of the illustrated concept is that of utilization of small, inexpensive user antennas and equipment, making access to the network feasible for large numbers of small users.

Satellites in low orbits are particularly useful for multinational service since their orbits overfly all nations. Two initiatives also applicable to government applications are leading examples of truly international systems: they are passive RF reflector space systems which are used to achieve over-the-horizon radar for air traffic control, and the distribution of electrical energy to substation-sized using areas.

The use of a number of reflecting or diffracting orbital passive structures for achieving over-the-horizon radar capability is illustrated in Figure 4-39. In this illustration, the orbiting diffracting arrays are

- **PURPOSE**
  To extend radar coverage beyond the line-of-sight for Air Traffic Surveillance, and avail other countries of the same satellites.
- **RATIONALE**
  Radars are costly and many are required today due to line-of-sight limits.
- **CONCEPT DESCRIPTION**
  Orbital diffracting passive arrays allow large coverage from a few central radars. Scanning accomplished by orbital motion and frequency shift.
- **CHARACTERISTICS**

• WEIGHT	3,700 lb
• SIZE	250 x 250 ft
• RAW POWER	1 kW
• ORBIT	300 nmi, 35-50°
• CONSTELLATION SIZE	150
• RISK CATEGORY	I (Low)
• TIME FRAME	1985
• IOC COST (Space only)	330 M

- **PERFORMANCE**
  All aircraft equipped with 10 W beacons detected reliably for enroute control every 4 min. U. S. A. covered with three radars. Smaller countries need only 1 - 2 radars.
- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle
• ON-ORBIT OPERATIONS	Shuttle manipulator, automated or manual assembly/servicing
• SUBSYSTEMS	Attitude control, structure
• TECHNOLOGY	Ion thruster, structural rigidity
• OTHER	None

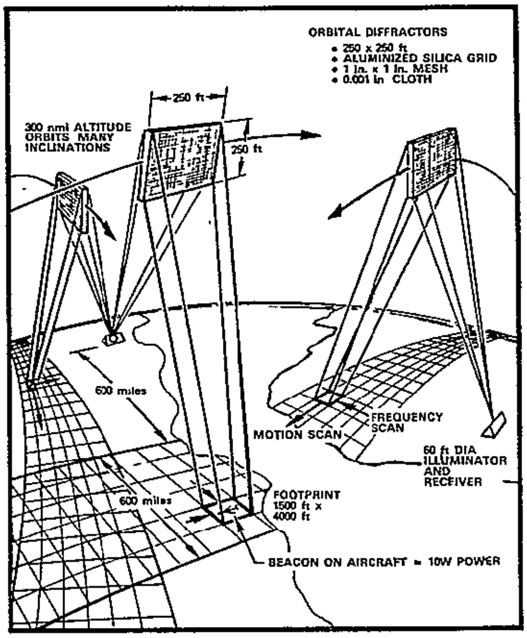


Figure 4-39. Multinational Air Traffic Control Radar (CO-5)

placed in low orbit, and can form the backbone of the en-route air traffic control system of the U.S.A. as well as all other nations. The large number of radars currently employed could be replaced with one or at most a few radars per large country, and the radar coverage swaths obtained by a combination of orbital motion and frequency scanning. Coverage of transoceanic routes would also be possible. The satellites are fairly light, but 100-200 are required to give a coverage of air traffic routes every few minutes. All nations could share the same satellites, and all beacon-equipped aircraft tracked nearly everywhere. The support requirements are satisfied by the shuttle, with manual servicing. This is a near-term low risk concept.

The second initiative, for energy distribution, was shown in Figure 4-33. Their funding, construction, development, and orbiting by the U.S. for our own use would make the satellites available to other nations when not over the U.S.A. Alternati vely, international funding could form the basis for even more cooperation. The control of the satellites could be leased, performed under lease, constitute a form of aid, or shared. In both initiatives the satellites could support a large number of nations, each of which would only have to install its own radar in one case, and its own power source/transmitter and rectennas in the second case. Developing nations could avoid laying transmission wires and proliferating air traffic control radars, thus by-passing one step in technological evolution. The global cost savings could potentially be very great.

The use of the aircraft laser beam powering scheme illustrated previously in Figure 4-34 , amounts to an energy common-user system with which the energy can be piped around the world using relay mirrors to power aircraft elsewhere, or the mirrors of Figure 4-34 can be utilized by other nations directly to power their own aircraft upon investment in their own laser ground stations. Ultimately a central space-based nuclear/ laser station could power all the world's aircraft.

The information from earth observation satellites could be made available to other nations for sharing functions such as resources, search, pollution detecting, crop yield prediction, earthquake prediction, land-use management, fire detection, water resources, etc., as described in previous initiatives. To this end, the observation data could be processed directly aboard the satellites when over the nation concerned, using powerful microminiature processors, with finished and formatted maps and other imaging being made available on a real-time basis directly to all interested parties within that nation. Alternatively, the data could be made available anywhere using data relay satellites.

The data could also be made available to the U.N. (or that body could purchase its own satellites) for many uses, but particularly one use is addressed separately - that is the use of satellites in establishing and policing cease-fire and truce lines in the U.N.'s peacekeeping role. To that end, a satellite concept is illustrated in Figure 4-40 in which visible light

- PURPOSE
  Aid U.N. teams to monitor truce agreements, particularly border zones, and weapon system dispositions such as missile launchers.
- RATIONALE
  U.N. will have responsibility for truce monitoring, but will be denied on-site capability in some cases. Space systems are free from local control or interference
- CONCEPT DESCRIPTION
  One low altitude satellite with visible light optics for daytime monitoring and infrared optics for night-time operation.
- CHARACTERISTICS

• WEIGHT	4,000 lb
• SIZE	15 x 60 ft
• RAW POWER	3 kW
• ORBIT	225 nmi near-polar
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1985
• IOC COST (Space only)	90 M

- PERFORMANCE
  Ground resolution, <6 ft. (Visible) 120-ft I.R. Location accuracy, 300 ft. Truce area covered twice a day.
- BUILDING BLOCK REQUIREMENTS

• TRANSPORTATION	Shuttle
• ON-ORBIT OPERATIONS	Shuttle attached manipulator
• SUBSYSTEMS	Focal plane
• TECHNOLOGY	Similar to weather satellites and ERTS; CCD focal plane
• OTHER	

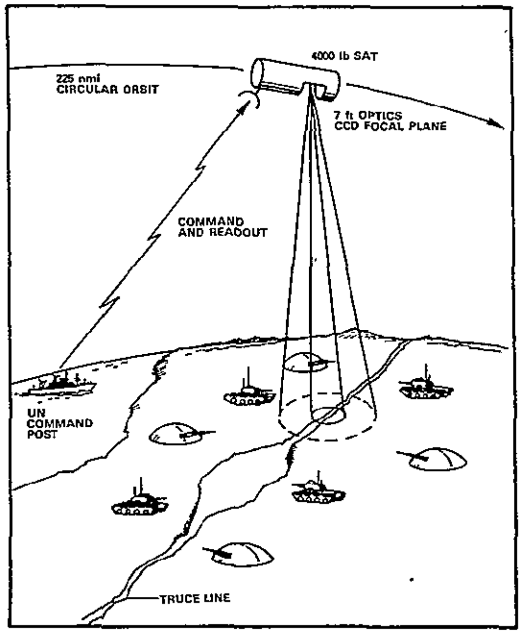


Figure 4-40. U.N. Truce Observation Satellite (CO-6)

and infrared imaging, with real-time readout, is used for use by the U.N. peacekeeping forces to monitor and assess compliance with truce agreements. A single satellite will allow imaging twice a day (one only in the infrared at night, with reduced resolution). A much larger, but more expensive, satellite would be able to image at night with no loss of performance, but is not described. The illustrated concept is low risk, and requires but the shuttle or expendable booster for launch and subsequent servicing.

Additionally, in the area of international cooperation in space, a start could be made in the next 25 years toward establishing options for eventually creating human colonies in space in order to relieve the population and resource pressures on earth; or toward orbiting permanent industrial facilities for support of space or earth operations. Meaningful programs toward such a goal could include experiments in long-term (years) habitation in a completely self-contained and isolated environment in a "space station;" the establishment of pilot plants; visitor centers, and other space facilities. These facilities are not reflected in the summation of supporting system needs in this report.

4.1.6 Scientific Applications

The synthesis and collection of system concepts in this study was aimed chiefly toward earth-oriented applications, however it is clear that the general principles of space application and the high leverage advanced technology discussed in Sections 2 and 3 also apply to purely scientific and extraterrestrial applications. Two such concepts are discussed below, along with a number of initiatives presented primarily for other application but which have scientific application as well. The following initiatives are discussed under this category:

1. Atmospheric Temperature Profile Sounder
2. Ocean Resources and Dynamics System
3. Water Level and Fault Movement Indicator
4. High Resolution Earth Mapping Radar
5. Astronomical Super Telescope
6. Interplanetary T. V. Link

The first four initiatives were mentioned previously in connection with other applications. The atmospheric temperature profile sounder was illustrated in Figure 4-17, could provide most quantities of data on the detail circulation of ocean currents, surface temperature distribution globally and its effects on atmospheric circulation, the diffusion of pollutants such as oil spills, the distribution of ocean flora and fauna, and other applications.

The initiative concept on water level and fault movement indicator illustrated previously in Figure 4-16, could provide valuable data on water cycle circulation, hydrologic resources, plate tectonics, detail geological processes, as well as provide accurate input to studies of estuary life and many other water level-dependent disciplines. Of course, high resolution imaging observations provided by several of the initiatives illustrated under government observations, can be used for scientific studies in geology, chemistry, hydrology, oceanology, and many specific applications in science.

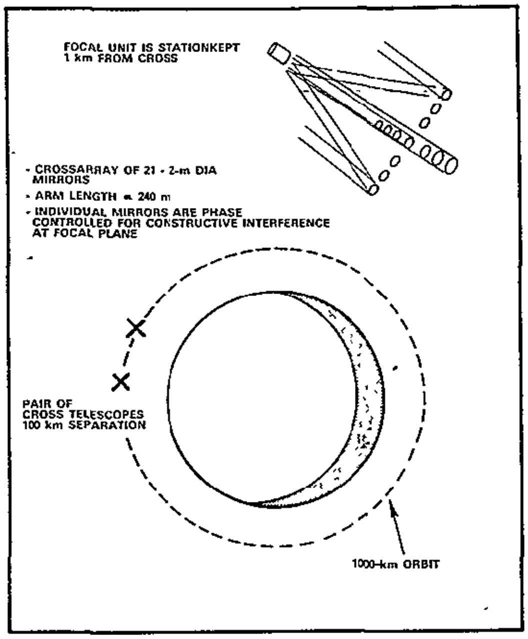
The technology of large aperture optics in space in particular suggests a new application to space telescopes. One such concept is illustrated in Figure 4-41, in which the technique of stationkept multiple mirrors is utilized to form a thinned crossed array with total arm length of 240 meters, with the mirrors individually and adaptively phase controlled by command from a central stationkept focal unit for constructive interference of the energy from the separate mirrors. The resolution of such a crossed array would be 2.5×10^{-9} radians. The use of a pair of such telescopes 100 km apart with a coherent laser link for energy addition, would result in optical resolution as small as 10^{-11} radians. Further use of a pair of telescopes located on opposite sides of a larger orbit might attain even smaller resolution. Unprecedented astronomical capability could be obtained from the use of such adaptively controlled stationkept thinned arrays. In particular, the illistrated capability of one crossed array would be sufficient for direct parallax measurement of stellar distances to 6,500 light years, with the equivalent capability of a pair of crosses being 650,000 light years. The technology is exceedingly difficult, with phase control required of each mirror separately. Such control could be obtained by suitable electrically stressed coatings on the mirrors, by mechanical motion of the front surface of each mirror with respect to its base (using piezoelectric or electrostatic actuation), or by the equivalent function performed closer to the focal plane at a distance such that the energy from each mirror is distinguishable from that of the others.

This telescope would likely be primarily useful for monoschematic point source astronomy, and is considered a high risk undertaking for the far term. Its support requirements are straightforward, however, being limited to the shuttle and manual assembly/initialization/servicing using the shuttle manipulator.

- **PURPOSE**
  To extend knowledge of universe by examination of most distant objects
- **RATIONALE**
  Largest earth telescopes have insufficient resolution. Need even more than LST will provide.
- **CONCEPT DESCRIPTION**
  A cross-array of visible light and 100 μm mirrors is phase controlled at mirrors or near focal plane for constructive interference. Laser link to other cross-array.
- **CHARACTERISTICS**

• WEIGHT	40,000 lb
• SIZE	800 ft cross
• RAW POWER	10 kW
• ORBIT	300 nmi circular
• CONSTELLATION SIZE	2-100 km apart
• RISK CATEGORY	IV (High)
• TIME FRAME	2000
• IOC COST (Space only)	430 M

- **PERFORMANCE**
  Direct parallax measurements to 6500 light years with one cross Resolution of one cross = 3×10^{-9} radians. Resolution of 2 crosses = 10^{-11} radians.



- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle
• ON-ORBIT OPERATIONS	Automated or manual service unit, manned assembly
• SUBSYSTEMS	Mirrors, stationkeeping, structure, sensor, phase control mechanism
• TECHNOLOGY	Adaptive focal plane, mirrors, stationkeeping sensors
• OTHER	

Figure 4-41. Astronomical Super Telescope (CO-10)

The last example of scientific applications is that of high data rate interplanetary communications. Many mechanizations are possible - using large antennas and high power on planetary probe spacecraft, using large micorwave receiver antennas in each orbit, or passively reflecting the received microwave or laser energy in earth orbit into a ground receiver. The initiative discussed uses the best transmission frequencies for each path, namely laser light for the deep space to near-earth space link, and microwave for the near-earth-space to ground link. Such a concept, illustrated in Figure 4-42, allows the use of relatively small collector in near-earth orbit which collects about 10 orders of magnitude more energy from the transmitted beam than would a microwave link with the same aperture transmitter. The signal is collected, detected in a photomultiplier tube or CCD array, and used to modulate a microwave transmitter for transmission through the atmosphere, avoiding weather and atmospheric attenuation.

- **PURPOSE**

  To provide for color T.V., live reception over planetary ranges
- **RATIONALE**

  Complex missions and information needs will require live T.V communications
- **CONCEPT DESCRIPTION**

  Large reflector in synchronous orbit is used to detect laser energy from planetary probe, and modulates microwave transmitter. Signal detected by earth tracking station.
- **CHARACTERISTICS**

• WEIGHT	1,000 lb
• SIZE	50-ft dia
• RAW POWER	250 W
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1985
• IOC COST (Space Only)	40 M

- **PERFORMANCE**

  Live - 60 frames/second color T.V., commercial image quality (or equivalent) transmitted over 20 million miles to 60-ft ground antennas. 4 in laser and 10W suffice in transmitter.
- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle, IUS/tug
• ON-ORBIT OPERATIONS	Automated servicing
• SUBSYSTEMS	Thin film mirror
• TECHNOLOGY	Thin film self-supporting structure
• OTHER	

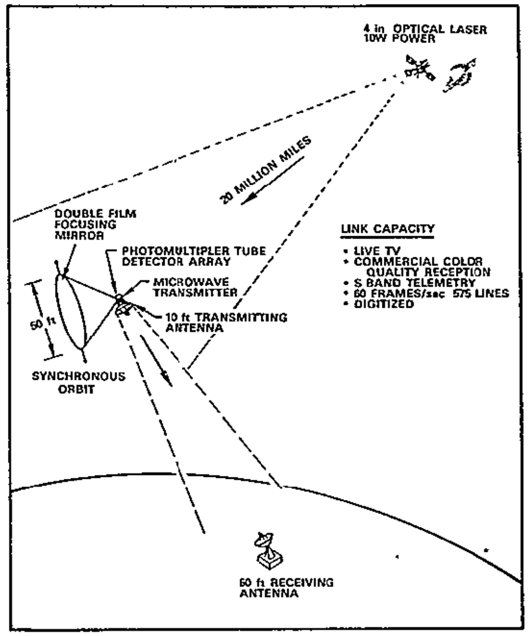


Figure 4-42. Interplanetary T. V. Link (CO-14)

The concept envisions the use of a thin-film collector 50-ft diameter, and a 10-ft diameter microwave transmitting antenna in synchronous orbit. A 10-W transmitter laser with 4-in. optical aperture in the planetary spacecraft suffices for transmitting digitized live color T. V. images of commercial studio quality over a distance of about 20 million miles. Such an initiative is considered low risk and near term, and could form the basis of a receiving station for all our planetary probes and expeditions for decades to come. A shuttle and IUS/tug would suffice to orbit it, and an automated servicing unit to keep it operating would insure its availability through the year 2000.

4.2 MILITARY INITIATIVES

The specific military initiatives collected and synthesized in this study are not shown in this unclassified report for security reasons.

However, summaries of the most significant characteristics of the initiatives when taken as a group can be discussed and are addressed in Section 4.3.

4.3 SUMMARY OF SIGNIFICANT CHARACTERISTICS

The initiatives presented and illustrated in Sections 4.1 and 4.2 should not be taken as individual proposals, nor is information presented to enable judgment on which ones are more desirable than others. The intent of the initiatives is primarily to illustrate the range of applications of the general principles and advanced technology presented in Sections 2 and 3. In this present section an attempt is made to collect descriptive features or characteristics of the entire group of initiatives taken as a set, for it is felt that whereas the characteristics of any one initiative may not be meaningful, those of the entire set should carry significant messages.

A first characteristic examined is the weight of the initiative satellites as a function of their orbital altitude which is plotted in the graph of Figure 4-43.

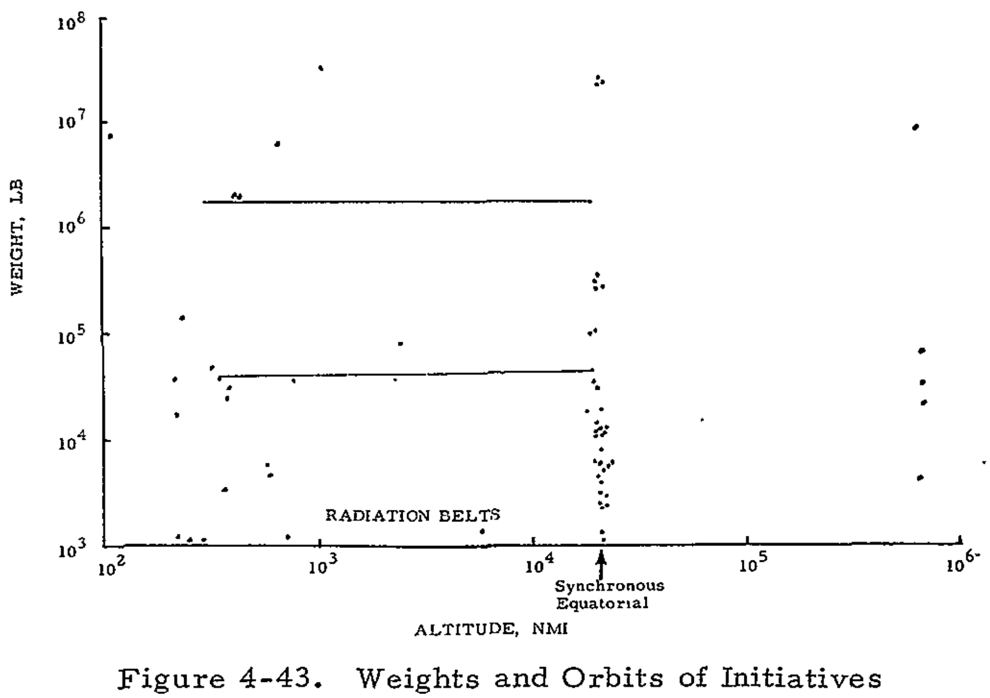


Figure 4-43. Weights and Orbits of Initiatives

Each initiative is shown as a point on the graph without any weight assigned to function, type, utility, or risk category. Both military and civilian initiatives are included but not identified. It is seen that great use is made of synchronous equatorial orbits with a large concentration of satellite weights in the order of a few thousand to a few hundred thousand pounds, with the solar and other energy generation and delivery initiatives contributing the heaviest satellites. There are quite a few satellites in low orbits, and are usually those where multinational features are needed, in which the cost must be absolutely minimized at the expense of coverage frequency, or those for which the use of higher altitudes would result in satellites so large that they could not be placed in any of the risk categories in the time frame considered.

There are few initiatives with orbits inside the radiation belt regions, not only for the obvious reason of radiation sensitivity, but because if the satellite sizes required at medium altitude are considered achievable in the time period, they are probably also achievable at synchronous altitudes, with fewer satellites being required and with simplifications (such as avoiding tracking antenna) probably compensating for the increased sizes. All of these reasons result in clustering of satellites in orbits at low and synchronous altitudes.

The weight as a function of projected area for several representative space systems, is plotted in Figure 4-44, using low altitude and high altitude as a parameter. Functional satellite types are shown for both low and synchronous altitudes. It is seen that although there is a general correspondence of weight with size, there is considerable scatter due to the widely differing densities of various satellites. The largest satellites are clearly in synchronous orbit, but in sizes below 3,000-ft dimension, the weights are about equally distributed between low and synchronous altitude.

The weight dependence of some of the unusual satellites of the initiatives is derived and presented in Section 5 of Volume III, and summarized in Figure 4-45.

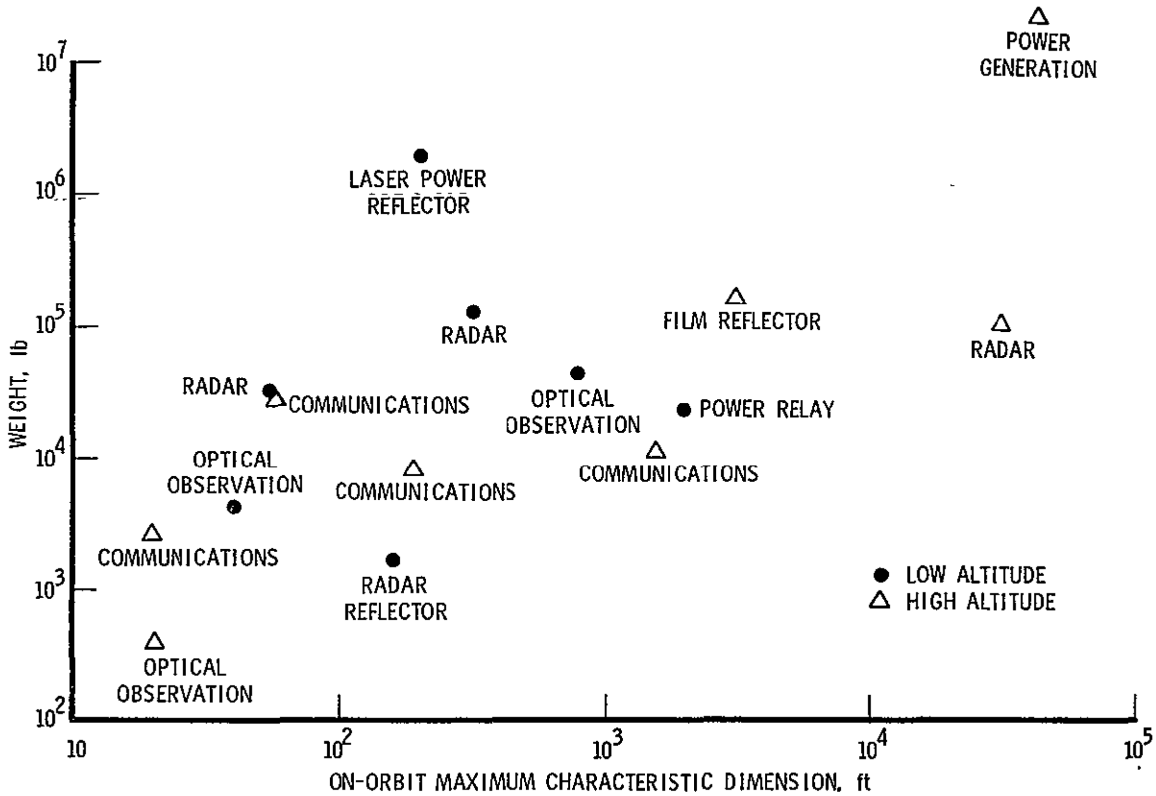


Figure 4-44. Major Parameters of Representative Concepts

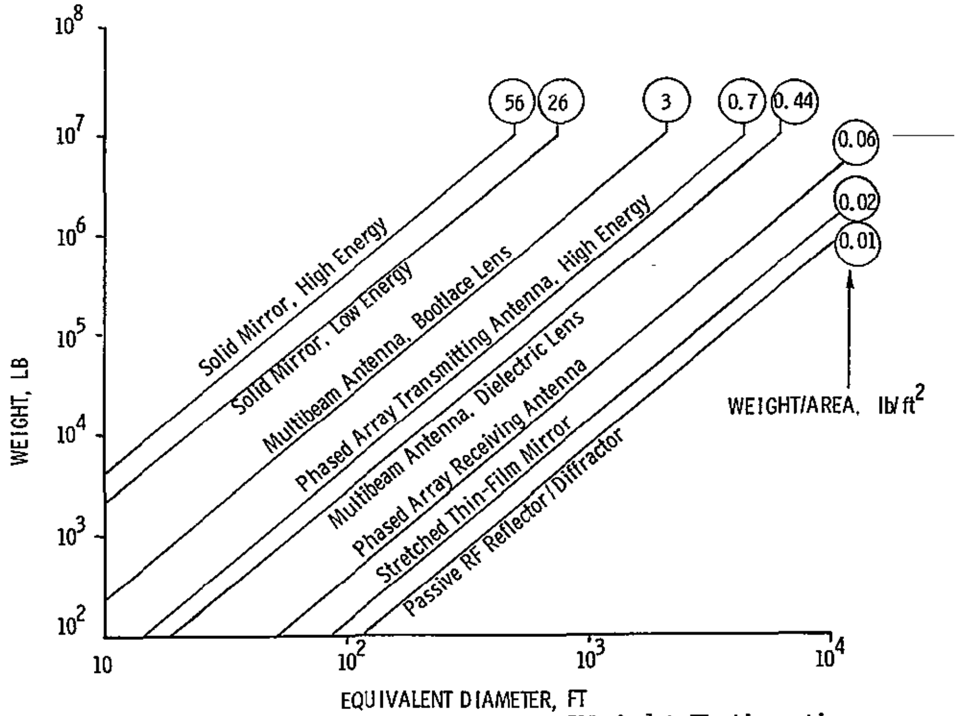


Figure 4-45. Large Structures Weight Estimation

It is seen that these satellites vary in density from more than 60 lb/ft^2 for the high power laser reflector, to about 0.01 lb/ft^2 for the passive RF reflector mesh satellites.

A somewhat different perspective arises when reviewing the applications of low vs. geostationary/high altitude orbits. As illustrated in Figure 4-46, the geostationary or high altitude orbits generally were used to serve applications which require quasi-continuous coverage of the U.S.A., such as is the case for a large portion of the applications to personal, civic, and domestic government services. In general, a single satellite can meet a given domestic need or perform a service, and since the advent of economical space transportation, is usually a less costly approach than many satellites in low altitude orbit. The satellites are generally large, but allow the ground users to be small, cheap, and in greatly proliferated numbers, making the total of space plus ground costs a minimum.

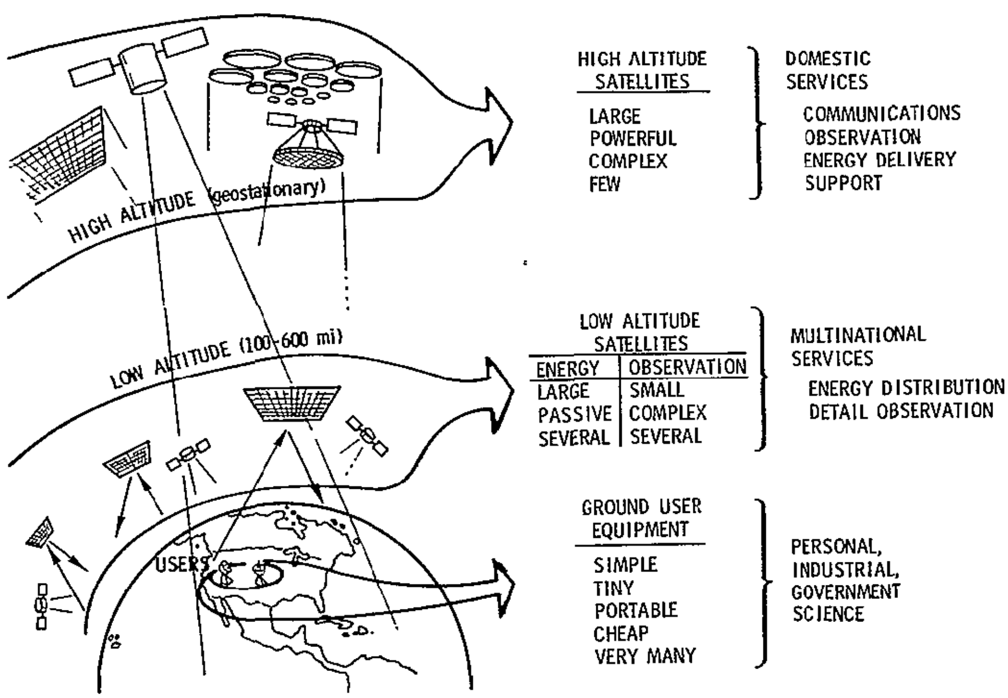


Figure 4-46. Guiding Principles for Space Applications

In contrast, low altitude orbits generally find application to multinational uses in such services as mapping, resources search, energy distribution, air traffic control, aircraft powering, etc. In this case, the satellites' motion around the earth is used to advantage in minimizing the requirements on the satellites while simultaneously maximizing their global utility. The satellites are generally large passive reflectors or smaller active optical/microwave sensors, and many are required to obtain the required frequency of coverage.

A review of the initiatives indicates that the satellites illustrated generally fall into four different classes, being: multiple beam antenna/switching centers; long linear or crossed arrays; large area passive reflectors or mirrors; and a variety of active optical or microwave sensors/radar/lidar. These types are illustrated in Figure 4-47.

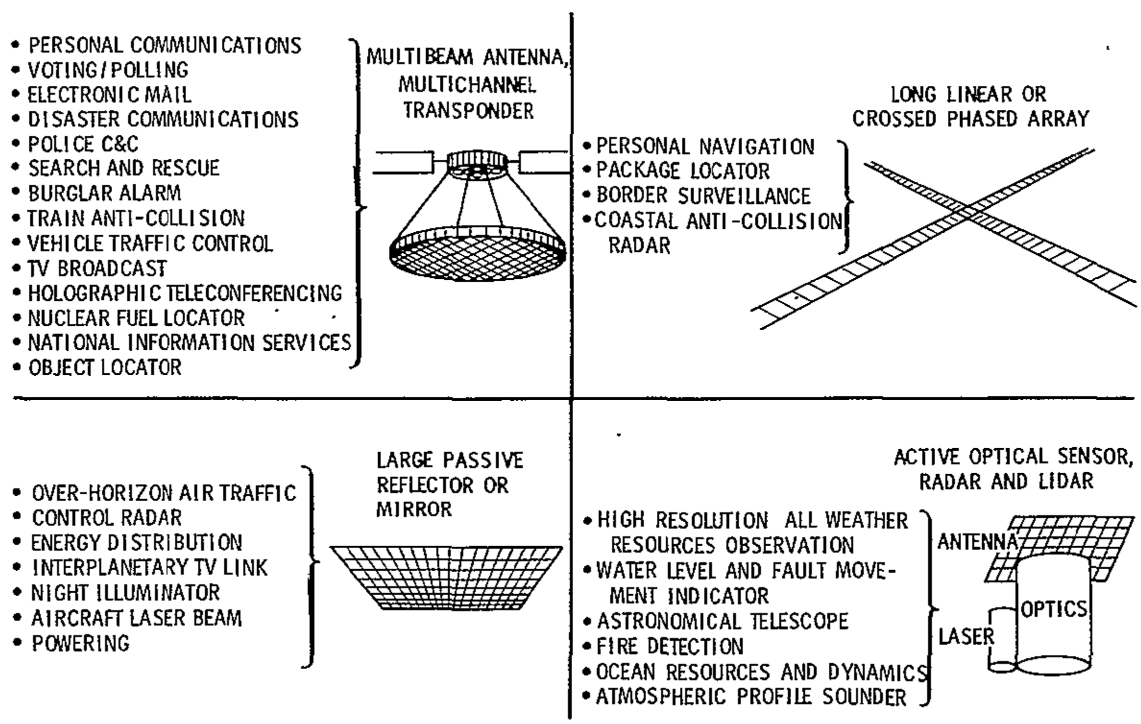


Figure 4-47. Multiple Function Satellite Types

It is seen that each type of satellite can support a number of different missions which have similar functional requirements. Multi-function satellites are therefore clearly possible, and some degree of function aggregation may be desirable for economic reasons, since servicing of the satellites has been assumed as a routine function, and thus the availability of any one function on a multifunction satellite need not be dependent on the availability of any other.

The same argument can be applied to user equipment types, and indeed, in small communication terminals, three generic types are identified. These are illustrated in Figure 4-48, in which several of the functions which could be supported by a single terminal or terminal type are identified.

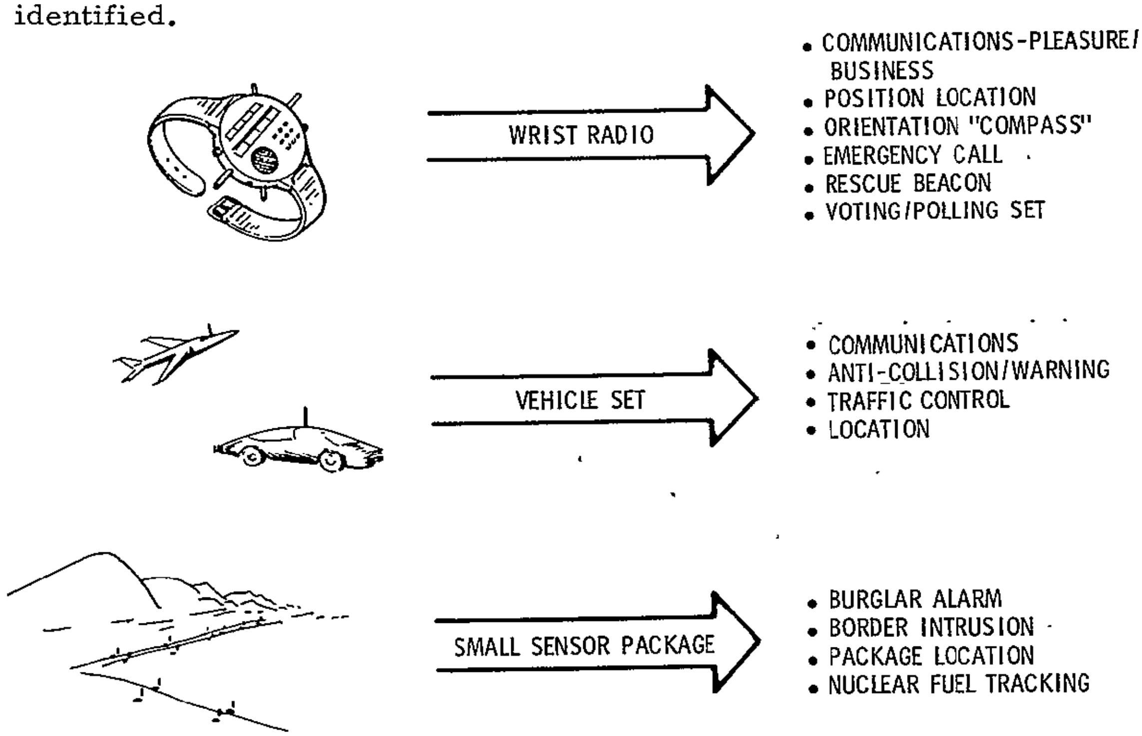


Figure 4-48. Multiple Function User Terminals

The resultant capabilities of the satellite systems as observed from this brief overview of the characteristics of the entire set are consistent with the intent of the general principles of space application proposed in Section 2.

5. FUNCTIONAL SYSTEM OPTIONS

The initiatives presented in the previous section, combined with systems from the NASA and DoD mission models, were organized into a time-phased functionally oriented data bank in order to allow construction of specific program plans, which in turn allowed the subsequent derivation of supporting needs.

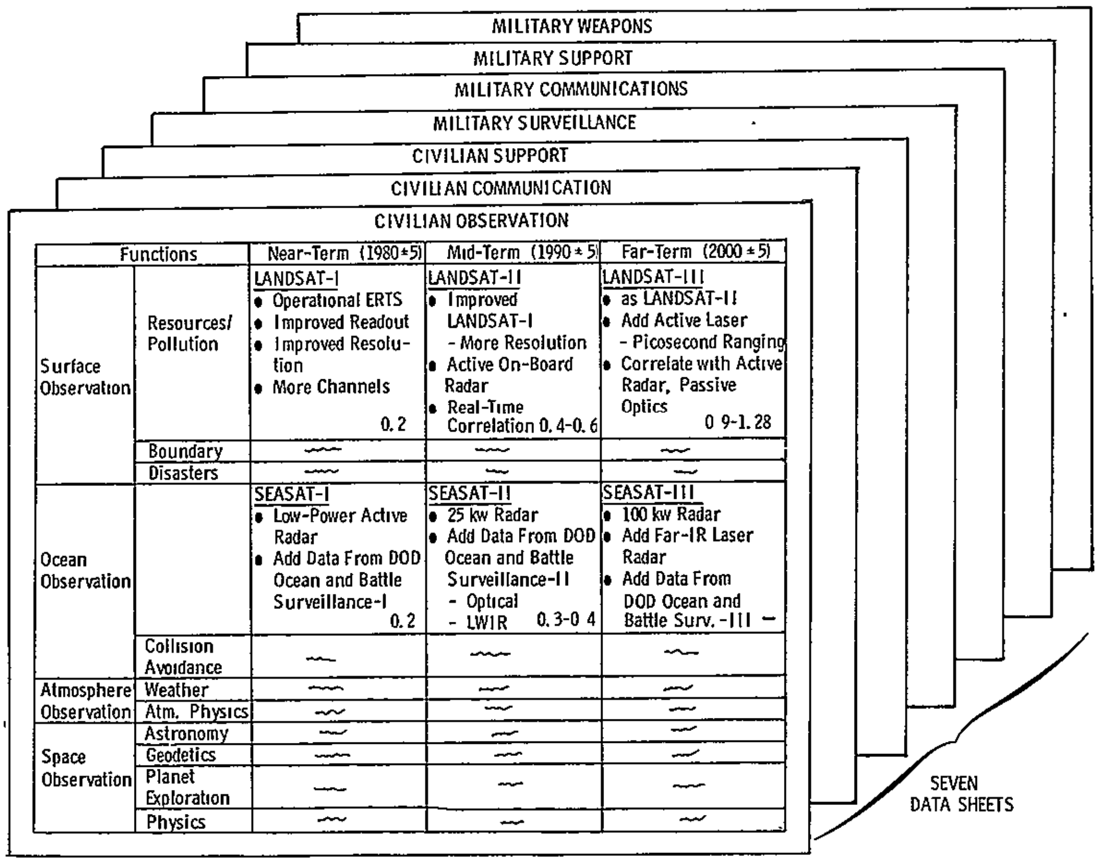
The functional organization scheme utilized is shown in Figure 5-1 for the civilian initiatives and systems, and Figure 5-2 for the military initiatives and systems. (Figure 5-2 omitted for security classification reasons.)

FUNCTION	ORIENTATION	SPECIFIC ACTIVITY
OBSERVATION	SURFACE	Resources/Pollution, Boundaries, Disaster Areas
	OCEAN	Sea State/Ocean Physics; Collision Avoidance
	ATMOSPHERE	Weather; Atmosphere Physics
	SPACE	Astronomy; Geodetics; Planetary Exploration; Physics
COMMUNICATIONS	INTERGOVERNMENT LINKS	International; Diplomatic
	GOVERNMENT/PEOPLE LINKS	Voting/Polling
	PEOPLE/PEOPLE LINKS	Personal
	INTRAGOVERNMENT LINKS	Routine; Emergency
	ENTERTAINMENT/COMMERCIAL LINKS	T.V., Mobile
SUPPORT	NAVIGATION	Vehicular; Personal
	TRANSPORTATION AID/CONTROL	Air/Sea/Ground
	ENERGY	Delivery; Management
	ENVIRONMENT MODIFICATION	Atmosphere; Weather; Illumination
	DISPOSAL AND CONTROL OF WASTES	Toxic/Radioactive
	NEW MEDIUM FOR RESEARCH AND MANUFACTURING	Dedicated; Incidental
	SPACE TRANSPORTATION DEVELOPMENT	Low, High; Planetary

Figure 5-1. Functions in Civilian Space Programs

PRECEDING PAGE BLANK NOT FILMED

The functional system options are then developed and presented in the form of seven data sheets, one for each of the major functions in the civilian and military areas. An example from this data bank of system options is presented in Figure 5-3. Each sheet contains the system options for near term, midterm, and far-term space projects which apply for each subcategory of functions to be fulfilled. For the purposes of this report, we define near-term as 1980 ± five years, midterm as 1990 ± five years, and far term as the year 2000 ± five years.



Functions		Near-Term (1980±5)	Mid-Term (1990±5)	Far-Term (2000±5)
Surface Observation	Resources/ Pollution	LANDSAT-I • Operational ERTS • Improved Readout • Improved Resolution • More Channels 0.2	LANDSAT-II • Improved LANDSAT-I - More Resolution • Active On-Board Radar • Real-Time Correlation 0.4-0.6	LANDSAT-III • as LANDSAT-II • Add Active Laser - Picosecond Ranging • Correlate with Active Radar, Passive Optics 0 9-1.28
	Boundary	~	~	~
	Disasters	~	~	~
Ocean Observation		SEASAT-I • Low-Power Active Radar • Add Data From DOD Ocean and Battle Surveillance-I 0.2	SEASAT-II • 25 kw Radar • Add Data From DOD Ocean and Battle Surveillance-II - Optical - LWIR 0.3-0 4	SEASAT-III • 100 kw Radar • Add Far-IR Laser Radar • Add Data From DOD Ocean and Battle Surv.-III –
	Collision Avoidance	~	~	~
Atmosphere Observation	Weather	~	~	~
	Atm. Physics	~	~	~
Space Observation	Astronomy	~	~	~
	Geodetics	~	~	~
	Planet Exploration	~	~	~
	Physics	~	~	~

Figure 5-3. Functional System Options Data Bank

The functions in civilian observation are shown as an example, with the subcategaries of surface observation for resources and pollution, and ocean observation detailed. The system options shown in the example are synthesized from the initiatives developed in Volume III of this report, the NASA and the DoD STS Mission Models, and other information from past NASA and DoD planning studies. The definitions of alternate or follow-on programs such as "LANDSAT-I, II, and III" were developed by the authors for this particular report and have no official significance. As an example of the system options, the near-term LANDSAT-I is assumed to be an operational Earth Resources Test Satellite with somewhat improved readout and resolution from the current LANDSAT. LANDSAT-II is assumed to be a further improved LANDSAT-I with much more spatial and spectral resolution, incorporating an active on-board radar with a synthetic aperture array and real-time correlation of the passive and active signals either on board or off board. LANDSAT-III, which is a far-term program, is assumed similar to LANDSAT-II except for the addition of an active mode-locked laser radar with pico-second pulses for $\pm$ 0.3 mm ranging capability, and correlation between the active radar, the active lidar, and the passive optics on board. The numbers at the bottom right-hand corner of the near-term, midterm, and far-term system options are the estimated costs of R&D, acquisition, and transportation for establishment of the required constellation of each of the system options, measured in billions of dollars. No operational costs are included in these numbers, and the numbers are assumed to be in constant 1975 dollars.

Similarly, SEASAT-I is assumed to be a low-power active radar similar to the currently proposed SEASAT program, with data added from assumed DoD surveillance programs as appropriate. In the midterm SEASAT-II, the power of the active radar is assumed to increase to 25 kW, with imaging in optical-through-infrared, should such systems be simultaneously selected for a program plan, as well as data from more advanced versions of military surveillance satellites. SEASAT-III is assumed to have an increase in power to 100 kW with the addition of a far-infrared laser radar for possible imaging through clouds, as well as data added from the far-term equivalent military space surveillance system if available. Thus, the data bank of system choices for program plans shows capability increasing with time, and is composed of components ranging from single initiatives to combinations of various civilian and military initiatives.

The entire data bank is contained in Volume III.

6. SPACE GOALS AND NEEDS IN THE FUTURE ENVIRONMENTS

Consideration was given to the international and domestic environments which were likely to exist in the 1980-2000 time period. The sources were primarily discussions with knowledgeable people, previous thought in this area, review of literature dealing with general forecasting, and specific reports and books addressing the subject. However, these views must be considered those of the authors, not necessarily endorsed by NASA or other Aerospace Corporation personnel.

The purpose of this consideration was to enable the interpretation of the environment in terms of the National goals, so that the specific goals or requirements for space systems could be related to the roles they would play in support of the National goals.

6.1 CIVILIAN ENVIRONMENT AND GOALS

Great changes in the international and domestic environment are expected in the time period, grossly affecting the domestic attitudes and goals. These will in turn have an impact on acceptance or needs for space systems. The following outline introduces these thoughts.

6.1.1 Some Key Aspects of the 1980-2000 Period as Related to Goals of U.S. Space Programs

a. U. S. World Interactions

1. High and Growing U.S. Material Wealth Compared to Remainder of World:

   - U.S. agriculture, because of combination of rich soil, favorable climate, advanced technology, and supportive government institutions, will be outstandingly productive, and provide large surpluses over domestic needs.

- U.S. industry will continue exponential growth at a diminished percentage rate of increase, but with absolute increase per year larger than any other nation.
- The U.S. wealth vs. the relative poverty of about two-thirds the world population, and the disproportionate U.S. use of global resources, will become an even more important irritant in international relations.

<u>Impact for Space Program</u>

- International sharing of benefits of space programs will help to ameliorate anti-U.S. feelings engendered by disproportionate U.S. wealth and consumption of resources.

2. International Economic Interdependence:

- U.S. economy will become more and more complicated. Both because of special materials needed by the U.S. technological society from the rest of the world, and because of the balance that foreign markets provide, the U.S. economy will become more dependent on foreign nations.

<u>Impact for Space Program</u>

- In some areas, space programs can reduce U.S. dependence on foreign nations. Again, by sharing space benefits, some interdependence in specific areas may be made more workable and even desirable as a basis for peace by shared economic interests.

3. Impact of U.S. Economy and Culture on the Internal Affairs of Foreign Governments:

- While individuals in foreign countries may profit by relations, be attracted to the culture, and desire closer friendship with the U.S. (and even personal participation in shared space programs), governments may feel threatened and so tend to exclude the U.S. from direct effects on their citizens.

4. International Peace:

- This issue will remain as complicated as ever, with nations in variable and possibly even labile positions. It will on occasion engender, and on occasion kill, cooperative international space ventures.

b. U.S. Internal Relations

The space program will have to be evaluated on the basis of a number of largely emotional factors as well as economic competition with other programs in a National Priorities list. Some of the factors which will have major influence include:

1. No easy consensus on domestic goals or policies.

2. Dichotomic relationship of citizens to government:

   Desired:

   - Less government influence on private lives, activities, jobs, economic activity.
   - Government non-interference with business, and with economic development.
   - Less government regulation.

   But also desired:

   - More government planning.
   - More government control of economic predation.
   - Government guaranteed economic welfare.

3. Dichotomic relation within society:

   - Desire and respect for cultural diversity.
   - Demand for social conformity.

4. Condition of "The Establishment:"

   - No clear identification of any group as really belonging to the establishment.
   - Establishment is a labile consortium of economic, political, intellectual, and religious interests -- largely centrist orientation.
   - Most people may feel disenfranchised from the establishment -- "only other interests belong."

5. Personal concerns overwhelm national and international concerns. Neo-isolationism not from principle, but from lack of sustained interest.

6. Fracturing of social structures with many pressure groups within groups. Labor no longer monolithic.

7. Lack of compelling national goals, frustrated vision of national greatness, dryness of national accomplishments, denigration of national efforts may be the pre-dominant feeling of the U.S. citizen.

8. Citizen feelings that space benefits scientists, technologists, and limited interests, but is of comparatively little benefit to the average person.

As a result of these and other aspects, a series of significant problems was identified, and is summarized below:

6.1.2 Significant Problems of the 1980-2000 Period

a. International

1. Overpopulation and disappearance of expansion space.

2. Limitations on fundamental natural resources by current or planned methods of exploitation.

   - Limited oil and natural gas
   - Limited supply of specific minerals - uranium
   - Potential exhaustion of world fisheries

3. Disaffection of non-industrial world with affluence and high level of consumption of U.S.

4. International conflict, strife, warfare.

b. National

5. Intermediary term optimization of industrial activity. Cost-benefit balance in exploitation or conservation.

6. Stable energy supplies at adiabatically adjusting prices.

7. Management of agricultural resources to provide dependable, bountiful domestic supplies and surpluses for foreign consumption at adiabatically adjusting prices.

8. Government responsibility for health and safety.

9. Frustrated vision of national greatness with morality.

10. Universal feeling of exclusion from the "Establishment."

6.1.3 Major Space Contributions to National Goals

The foregoing environments and problems lead to a series of space-specific goals to support National goals in the time period. The National goals tend to be fairly invariant, and their space-related portions are shown in Table 6-1.

Table 6-1. Major U.S. Goals in the Exploitation of Space

1. Promotion of International Peace
2. Enhancement of U.S. Influence in International Relations
3. Aid to National Defense
4. Promotion of Economic Welfare
5. Conservation of Natural Resources
6. Aid to the General Safety
7. Enhancement of Individual Satisfaction
8. Increase of Scientific Knowledge

A set of three specific tables was also developed, relating the space functions to be performed in support of specific National goals. The tables represent potential contributions to goals relatable to public service and humanistic motivations; those relatable to materialistic motivation, and those relatable to intellectual pursuits. These specific potential contributions are shown in Tables 6-2, 6-3, and 6-4.

A review of the above tables indicates that space could contribute in goals affecting a great many facets of people's lives, as well as industry, government at all levels, international relations, and intellectual pursuits.

Table 6-2. Potential Space Contributions to Public Service and Humanistic Goals

GOALS	SPACE FUNCTIONS
1. Promotion of International Peace	• Treaty Verification • Nation-Nation "Hot Lines"
2. Aid to General Safety	• Disaster Warning and Control • Drought Prediction • Transportation Safety Control
3. Protection of the General Environment	• Pollution Monitoring • Preservation of the Ozone Layer • Prediction of Ionospheric Disturbances • Preservation of Near-Space Environment
4. Individual Aid and Protection	• Personal Communications, Emergency, and Routine
5. Aids to Crime Control	• Night Illumination and Searchlights • Police Communications and Control • Traffic Control
6. Internal Security	• Border Surveillance Against Illegal Entry • Control of Nuclear Materials
7. Improved Relation of Citizens to Government	• Better Communications Access Between People and Government
8. Enhancement of Satisfaction	• Develop Pride in Significant Accomplishments

Table 6-3. Potential Space Contributions to Materialistic Goals

GOALS	SPACE FUNCTIONS
1. International Cooperation	• International Space Projects • Share Benefits of U. S. Space Projects
2. Aid in U. S. Position of World Leadership	• Demonstration of Innovative Problem-Solving; Mastering of High Technology; International Enterprises, etc.
3. Aid in Increasing Industrial Activity	• Resource Exploration • Pollution Monitoring • Weather Prediction and Control • Transportation Control • Communication Facilities • Energy Management and Generation
4. Aid in Agricultural and Forest Management	• Weather Prediction and Control • Crop Prediction • Forest Surveys
5. Provision of New Resources	• Energy Delivery
6. Acquisition of New Environment	• Large, High Vacuum • Zero g
7. Use of Space to Remove Hazards From Earth	• Perform Hazardous Processes • Disposal of Wastes

Table 6-4. Potential Contributions to Intellectual Goals

GOALS	SPACE FUNCTIONS
1. Aid in Determination of Origin of Solar System	• Planetary exploration and geology • Nature of asteroids • Cometary research
2. Aid in Understanding Galactic Structure and Dynamics	• Infrared astronomy 5-500 μm • Ultraviolet astronomy
3. Aid in Understanding Cosmology	• X-ray astronomy • Observation of distant objects • Intergalactic materials study
4. Verification of Physical Laws in the Large	• General relativity experiments • Invariance of velocity of light experiments • Experiments on homogeneity and isotrophy of empty space in the large
5. Verification of Basic Physical Laws in the small	• Precise measurement of gravitational constant • Precise measurement of equivalence of inertial and gravitational mass

6.2 MILITARY ENVIRONMENT AND GOALS

The international environment is the one most likely to affect the military space goals. Consequently that environment was examined in some depth, and is presented in Volume III, Section 3. A summary of a portion of that material is presented here, inasmuch as domestic goals in general and the civilian space program in particular cannot help but be influenced by the international environment.

6.2.1 International Environment

The general pattern of international power relations expected indicates a complicated picture of deterred nuclear war, but many lower-level tactical conflicts at an ever increasing pace. Table 6-5 summarizes the international picture expected to emerge in the 1980-2000 time period.

Table 6-5. Complex Pattern of International Relations 1980 - 2000

1. Five regional great power centers (three nuclear). -- Surplus areas. Remainder of world politically and economically fragmented -- Deficit areas.
2. Economic and cultural stress among great power centers.
3. Nuclear forces capable of multi-regional overkill. Nuclear conflict deterred. Non-nuclear conflict largely uninhibited.
4. Very severe stress in deficit areas, producing varied low level conflicts, several per year.
5. Multi-party maneuvering for advantage -- economic, political, ideological.

The general military goals, the specific military objectives, and the required military space functions which are appropriate for the above international environment are contained only in the classified version of this study report.

7. SUPPORT REQUIREMENTS

This section of the report derives and presents the requirements for space transportation, assembly and servicing stages, and orbital support facilities (lumped into the term "building blocks") and technology which match future needs. The method used in the study for developing such support requirements is discussed in the following paragraphs, with reference to the study approach outlined in Figure 7-1.

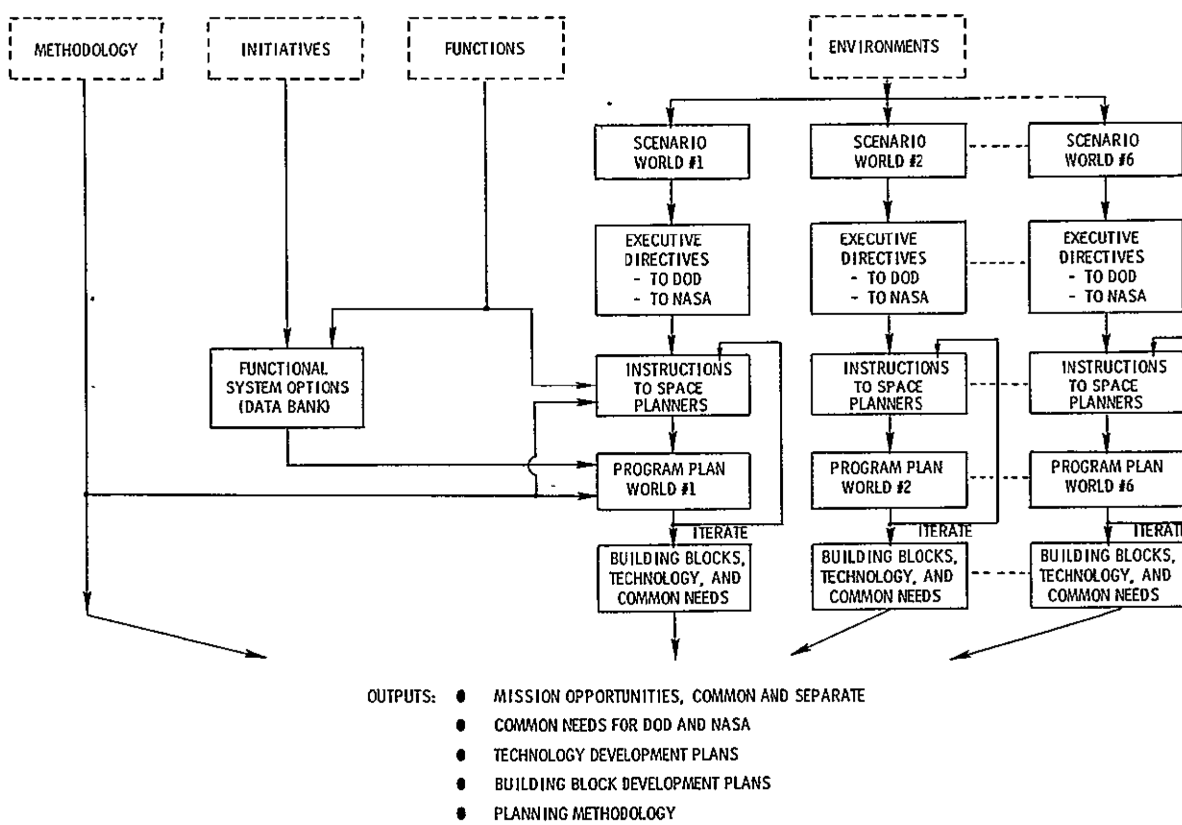


Figure 7-1. Outline of Program Planning Portion of Study

The outputs of the previous portions of the study were utilized in generation of the alternate world scenarios. For each scenario a set of executive directives was derived, intended for guidance to the NASA and DoD for structuring their programs consistent with the kind of scenario and the latent information in its definition. These executive directives were then amplified for each scenario resulting in specific instructions for the construction of program plans responsive to the scenarios, formatted using the functional system categorization scheme evolved in the first half of the study. Thus for each space function, instructions were developed to enable six alternate program plans to be generated.

The program plans were thus developed utilizing the specific instructions derived above to select initiatives from the functional system options data bank, which contains the initiatives collected and conceived ~~during the first half, as well as~~ initiatives based on the NASA and DoD mission models. These program plans were developed as a function of time, and their yearly cost was estimated. The sum of the costs of the program plans was then compared with the budget contained in the executive directives for the particular world being considered. If the costs of the program plan were grossly different than the budget requirements in the particular world, the program plan generation method was iterated until a rough correspondence was obtained.

Once the six alternate program plans were thus generated, supporting "building block" transportation vehicles, orbital support facilities, and needed technologies were extracted for each program plan. It was this information which was utilized for assembling the output of the study, i.e., the separate and common NASA/DoD needs for building blocks and technology for each particular world considered, as well as general development plans for systems, building blocks, and technologies which protect most of the options and are not dependent on particular assumptions of the future.

This section is organized as follows:

7.1 Alternate World Scenarios
7.2 Planning Directives
7.3 Program Plans
7.4 Budgets
7.5 General Support Needs
7.6 Specific Support Needs

The discussion begins with Section 7.1 which presents the alternate world scenarios, and continues logically through the support needs required under the conditions of each scenario.

7.1 ALTERNATE WORLD SCENARIOS

In order for a methodology based on future world scenarios to be useful, it must be based on views of the future encompassing a large spectrum of possibilities, both domestic and international, which include most of the reasonable options which significant numbers of authorities would be likely to include if they were questioned. That is a very great order indeed, and clearly can only be approached, particularly in a very limited study such as this. Consequently, the scenarios were constructed from two main sources of information. The first contained the views of the future developed in the first portion of the study from discussions with selected, informed, and authoritative people including members of the scientific community, government, industry (a list of people contacted for discussions is contained in Volume III, Appendix A); a review of documentation published in long-term projections or long-term views of the world environment projected to the end of the century; and in-house thoughts in this area. The draft resulting from that effort was checked against the second source: the "Outlook for Space" study portion on future world environments. The Outlook for Space study made a very comprehensive and thorough investigation in this direction. Some of the pertinent material that was developed by the responsible working group as well as some raw tapes from the Smithsonian Institution Symposium on Future Environments were reviewed as a second major source of inputs. It was felt that generally there was very little discrepancy between the gross notions of the future developed in the first part of this study and those which were generated by the Outlook for Space future environment investigation. This study, of necessity, was broader than that of the Outlook for Space since it had to include the international ideological and military environment in considerable depth. On the other hand, this study was not able to be as deep, thorough, and detailed in the world situation in general and in the domestic situations in particular, as the Outlook for Space study.

The combination of data sources discussed above engendered the feeling that while the future could not, of course, be predicted, a reasonable feel for the likely trends in areas crucial to program planning was obtained; and while no claim for the uniqueness of the conclusions is made, they are unlikely to be grossly in error.

Six futures were chosen in this study, representing combinations of three levels of international tension and four domestic environments. The scenarios and their gross implications are shown in Figure 7-2.

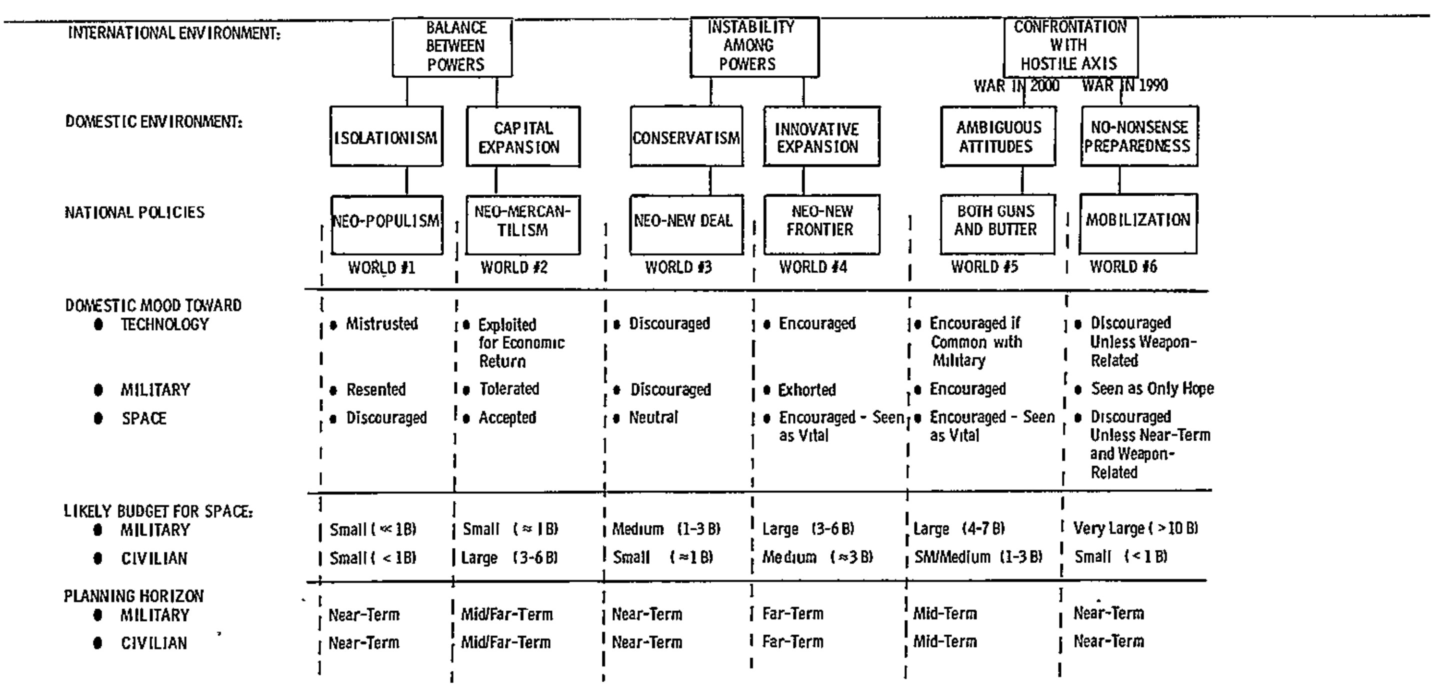


Figure 7-2. Spectrum of Representative Scenarios

The first two scenarios represent a balance in international relations between the major powers, combined in the first scenario with an isolationist domestic environment and in the second scenario with an expansionistic domestic environment. The third and fourth scenarios represent an unstable, maneuvering international balance, combined in the third scenario with a conservative domestic environment and in the fourth scenario with an innovative expansionistic domestic environment. The fifth and sixth scenarios represent a sure confrontation with an axis of hostile powers, leading to general nuclear war in the year 2000 in the fifth scenario, and in the year 1990 in the sixth scenario. The respective domestic environments are attitudes of ambiguity in the fifth scenario and no-nonsense preparedness for the coming holocaust in the sixth. These scenarios are discussed in more depth in Volume IV.

The scenarios described above probably span the spectrum of international and domestic situations which will define the U.S. environment in the period 1980-2000. No position was taken as to which world we are currently in, which world is most likely, or whether any world described is likely or realistic. However, it is reasonable to state that this spectrum is probably broad enough to include many of the dominant features of likely developments in international and domestic situations for the next 20-25 years; but the exact shape of those developments is not known, probably not predictable, and not required for this study. It was the aim of this spectrum of scenarios to enable the generation of a set of program plans from which information could be extracted applicable to any future world which is likely to exist. This spectrum of representative scenarios was thus utilized as the departure point for derivation of the program plans, and was central to the methodology adopted in this study for derivation of likely common needs for supporting space operations of NASA and DoD in the 1980-2000 time period.

7.2 PLANNING DIRECTIVES

In order to construct program plans, the six scenarios were interpreted in terms of executive directives for the military and civilian establishments, as might be issued by the executive branch of the government, as well as in terms of specific instructions to space program planners within each agency, as might be issued by the agency chiefs. The executive directives include general guidance on budget, time-frame stability, reliance on the other (civilian, military) establishment's programs, emphasis to be placed on innovation, and emphasis to be placed on the role of man in space. Specific guidance was also included on the magnitude of effort expected in earth-oriented applications versus exploration, science, and technology for civilian agency guidance; and on the rules of strategic versus tactical forces and those for defense of the homeland, for military agency guidance. Each world number (synonymous with a scenario number) resulted in one set of executive directives to the NASA and the DoD. The specific instructions to the program planners addressed, for each function, category, and subcategory of function, the magnitude of the effort, the emphasis on near-versus mid-versus far-term activity, and the degree of dependence or commonality with the other agency. Each of these three factors was spelled out for each of the six alternate worlds. These executive and specific planning directives are shown in detail in Volume IV, and are illustrated in Figures 7-3 and 7-4. Together with the time-phased data bank of functional system options of Volume III, they allow the preparation of alternate program plans, one for each alternate world scenario.

		WORLD #1	WORLD #2	WORLD #6
Time Frame Stability		Status-quo for 25 yrs.	Rapid growth for 25 yrs.	War in 1990; further planning not possible
Planning Horizon/Space Budget		Near-term/ < 1B	Mid-/far-term/ 3-6B	Near-term/ < 1B
New Starts		Few	Many, whenever economic payoff indicated	None solely civilian
Reliance on Military Programs		Utilize military technology to max. extent	Emphasize common use, but reliance not req'd.	Rely totally on military or fallout
Emphasis on Innovation		Minimize	Emphasize for clear economic payoff	None
Emphasis on International Programs		Minimize	Emphasize, encourage	None, except for communication between allies
Role of Man in Space		Little, if any	Large, whenever economically justified	Only for military payoff
Earth-Oriented Applications	Materialistic	Small effort	Large effort	Small effort, unless immediate military payoff
	Humanistic	Very small effort	Large effort	Very small, if any
Exploration		None	Large effort	None
Science		Very small effort	Large effort	Minimum, unless immediate military payoff
Technology		Minimum supporting activities	Large effort - lead the world	Minimum, unless immediate military payoff

Figure 7-3. Civilian Space Program Executive Directives

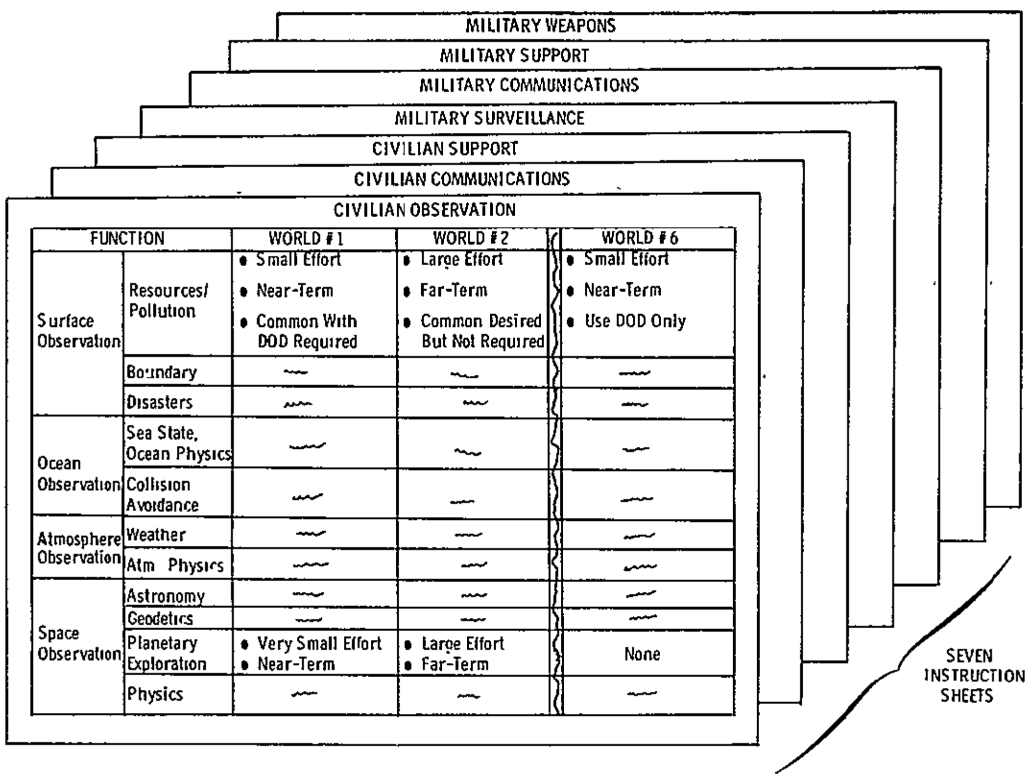


Figure 7-4. Instructions to Space Program Planners

7.3 PROGRAM PLANS

Forty-two program plan data sheets were prepared using the functional categorization and functional system options developed in Section 5, together with the planning directives described in Section 7.2 above. The format and content of the program plans is illustrated in Figure 7-5.

Each program plan is a sheet on which the activity level and time sequencing of each subcategory of space function taken from the system options data bank is shown. Also shown are the costs of each of the programs in terms of acquisition, operations, total costs, and an average of the total costs divided by the number of years which the program plan spans (most of the plans span 25 years). This last average cost is derived in order that the summation of all the average costs of all the programs may be added for comparison to the average yearly budget permitted as described in each alternate world scenario.

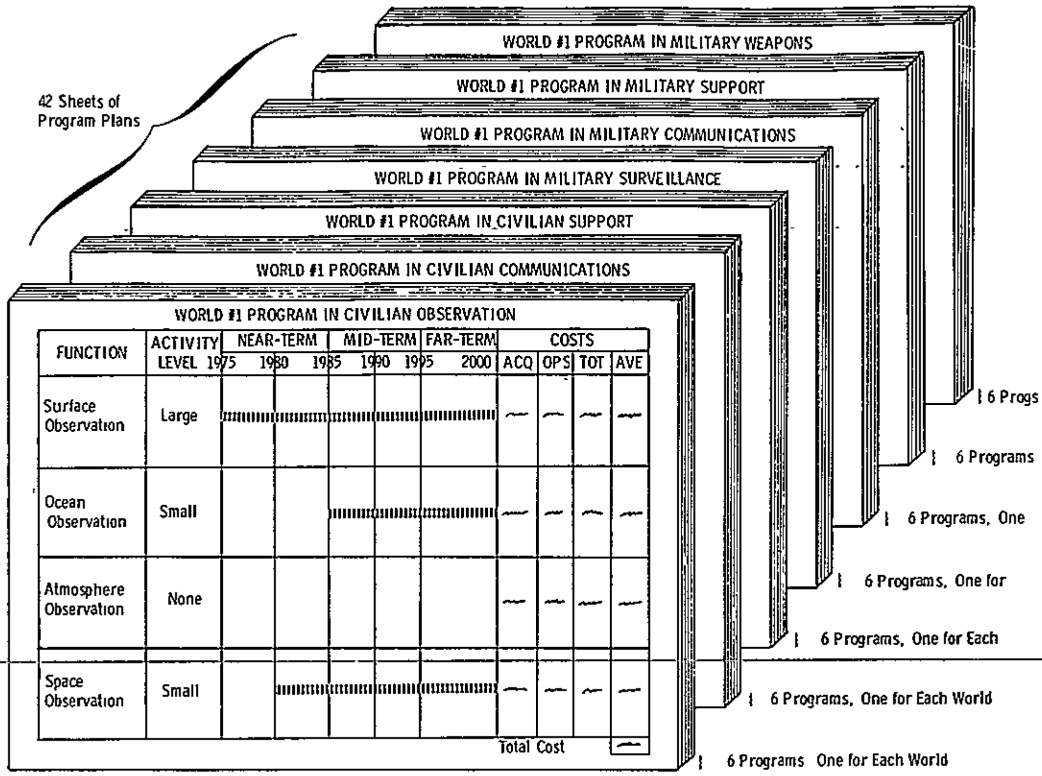


Figure 7-5. Program Plans

One program plan sheet was developed for the conditions of World #1 for each of the seven major functional categories: military and civilian observations; military and civilian communications; military and civilian support; and military weaponry. Each is repeated for the other five alternate world scenarios. Thus, six program plans were developed for each major functional category, and 42 program plans were developed in all. The specific instructions in the planners' directives were followed and influence the choice of near-term, midterm, or far-term functional system option which was chosen for inclusion in a particular plan. Where there was a range of costs associated with a given system option, the instructed activity level was used to choose the funding for the program which is shown in the cost columns of the program plans, a large activity level reflecting a choice of the larger of the budget estimates for that system option for that time frame.

An iterative procedure was followed in which all the program plans were developed based on the guidelines of the "instructions." Then the costs were added up for all functional components of each of the program plans and compared with the budget assumptions appropriate for that world. If the resulting costs of the program plans so generated differed markedly from the assumed costs, the program plan was changed within the guidelines of the instructions, so as to coincide more closely with the budget assumptions.

The complete set of program plans is contained in Volume IV. Two civilian plans (for observation in Worlds #1 and #2) are discussed by way of illustration of the contents of the entire set.

7.3.1 World #1, Civilian Observation

Figure 7-6 describes the program plan for civilian observation for World #1. The program is seen to contain mostly near-term systems which are deployed and operated for the rest of the century, a condition obtained from the National mood in World #1 which was defined as

FUNCTION		ACTIVITY LEVEL	NEAR-TERM / MID-TERM / FAR-TERM (1975 1980 1985 1990 1995 2000)	COSTS ACQ	OPS	TOTAL	AVG
SURFACE OBSERVATION	Resources Pollution	Small	LANDSAT-I — OPERATE →	0 2	0 6	0 8	0 032
	Boundary	Moderate	Intrusion Channels Alarm-I (ATS-F/G Leased Comsat 10 W Sensors) →	0 1	0 3	0 4	0 016
	Disasters	–	No Program (Use ERTS DSP)	---	---	---	----
OCEAN OBSERVATION	Sea State, Ocean Physics	Very Small	SEASAT-I (Low Power Radar) — OPERATE →	0 2	0 3	0 5	0 020
	Collision Avoidance	–	No Program	---	- -	- -	----
ATMOSPHERIC OBSERVATION	Weather	Small	Continue TIROS, NIMBUS, SMS — OPERATE →	---	0 6	0 6	0 024
	Atmospheric Physics	Very Small	Continue NIMBUS — OPERATE →	---	0 2	0.2	0 008
SPACE OBSERVATION	Astronomy	Very Small	Continue OAO OSO Cancel HEAO →	---	0 3	0 3	0 012
	Geodetics	Very Small	Continue OGO, GEOS, Cancel all Others →	---	0 3	0 3	0 012
	Planetary Exploration	–	No Program	---	---	---	----
	Physics	Very Small	(See Separate Sheet)				0 028
			SUB TOTAL				0 152

Figure 7-6. World No. 1 Program in Civilian Observation

anti-technology, anti-space, highly isolationist, and where the planning was all near term for immediate fallout benefits to the population.

The programs in physics, geodetics, and astronomy are very small as are observations of the ocean state and atmospheric physics; and small programs are shown for resources, pollution, and weather, the rationale being that new technology is not necessary with a return to inward-oriented basics, and that the first generation devices will yield adequate data. The only program which is even moderate sized is that of boundary observation because it is assumed that with the extreme trends to isolation a somewhat overriding concern for border patrol may be developed in the population. No programs are anticipated for disaster control or collision avoidance, collateral use of other programs being assumed. Planetary exploration is also nonexistent in such an inward-oriented society. The bulk of the programs imply continued current activities and some even at a quite reduced level.

The costs of this program plan reflect the low level of space activity in World #1, with an average cost for the entire observation program for the civilian community being $150 million a year. This program is obviously very austere but appropriate for the definition of the world and domestic environment which it reflects.

7.3.2 World #2, Civilian Observation

Figure 7-7 describes the program plan for civilian observation for World #2, which is the civilian environment in which all civilian space programs can flourish. The reason for this is that there is international peace coupled with a domestic spirit of exploiting the space medium to its fullest as well as satisfying intellectual and scientific curiosity. The activity level in each functional category and subcategory is seen to be large. Every program includes the near-term, midterm, as well as far-term system options from the data book of options in Volume III.

FUNCTION		ACTIVITY LEVEL	NEAR-TERM (1975–1985)	MID-TERM (1985–1995)	FAR-TERM (1995–2000)	COSTS ACQ	OPS.	TOTAL	AVG
SURFACE OBSERVATION	Resources Pollution	Large	LANDSAT-I, II, III (Radar →	Hi-power Radar → Picosecond	Laser) →	1.2	2.4	3.6	0.144
	Boundary	Large	Intrusion Alarm-I, II, III	(ATS-F → Multibeam Antenna →	Very Large Antenna)	0.4	0.6	1.0	0.040
	Disasters	Large	Disaster Control-I, II, III, (SEASAT Data → / LANDSAT Data →	Forest Fire Det / Ocean Battle Surv	Laser & Radar	0.5	0.8	1.3	0.052
OCEAN OBSERVATION	Sea State Ocean Physics	Large	SEASAT-I, II, III (Radar →	Hi-power radar → laser far	-IR correlate) →	0.4	0.4	0.8	0.032
	Collision Avoidance	Large		Bistatic radar	illuminator	1.1	---	1.1	0.044
ATMOSPHERIC OBSERVATION	Weather	Large	TIROS, NIMBUS SMS	• Improved NIMBUS • Hi-resolution Geosynchronous —	Operate →	0.4	1.0	1.4	0.056
	Atmospheric Physics	Large		Profilometer (Laser radar)	→	0.5	0.8	1.3	0.052
SPACE OBSERVATION	Astronomy	Large	• OSO • Explorers • HEAO → • LST	• Large radio observatory • Focusing x-ray obs • VLST • Large solar obs →	• 100 km radio telescope • 240 m optical telescope	5.0	4.8	9.8	0.392
	Geodetics	Large	LAGEOS, GRAVSAT, MAGNON, GEOPAUSE and Improvements	—	Operate →	1.5	2.4	3.9	0.156
	Planetary Exploration	Large	(See Separate Sheet)						0.472
	Physics	Large	(See Separate Sheet)						0.168
					SUB TOTAL				1.608

Figure 7-7. World No. 2 Program in Civilian Observation

As an example, in the resources and pollution area LANDSAT-I would be made operational as soon as possible and then augmented with or replaced by LANDSAT-II followed by LANDSAT-III in the far term, the far-term options being approached in an evolutionary manner. Similar examples can be made for each and every one of the functional programs on this sheet. Note that the average cost of this program is $1.6 billion per year as contrasted with less than $150 million in the program for World #1. Such an outlay is appropriate, given the nature of the world as previously defined.

7.4 BUDGETS

The average yearly cost of each program plan for each world number was tabulated at the time of composition of the program plans.

The average cost assumes that the peaks in funding can be appropriately spaced either by choice of the start and stop times of various programs and their phasing, or by some imaginative arrangement between Congress and the financial community such that the peaks are underwritten and amortized into all the years where less funding might otherwise be required. These average costs are compared in Figure 7-8 with the average yearly budgets assumed during the definition of each world number. The costs shown are the result of two iterations. Two conclusions may be drawn from Figure 7-8. In the first, it is seen that the program costs compare fairly well with the assumed budgets for each world number, since it is to be emphasized that no advocacy of any particular world is implied anywhere in this exercise. Nor is it assumed that any particular future world will occur or is more realistic than any other. Suffice it to say that the program plans defined by the 42 sheets appear representative of reasonable programs for Worlds #1 through #6 as defined, and that their costs are relatively well matched with the assumed budgets.

		WORLD NUMBER					
FUNCTIONS		1	2	3	4	5	6
MILITARY	OBSERVATION	0.036	0.246	0.342	1.58	1.11	1.84
	COMMUNICATIONS	0.052	0.14	0.247	0.572	0.344	0.4
	SUPPORT	0	0.138	0.158	0.66	0.439	4.89
	WEAPONS	0	0.036	0.68	2.23	3.47	6.17
	TOTAL	0.088	0.56	1.43	5.03	5.36	13.4
	ASSUMED BUDGET	≪1.0	≈ 1.0	1-3	3-6	4-7	>10
CIVILIAN	OBSERVATION	0.152	1.6	0.478	0.87	0.728	0
	COMMUNICATIONS	0.044	0.46	0.132	0.315	0.318	0.254
	SUPPORT	0.24	2.61	0.66	1.1	0.712	0
	TOTAL	0.436	4.67	1.27	2.28	1.76	0.254
	ASSUMED BUDGET	<1	3-6	≈ 1	≈ 3	1-3	<1

[1]COSTS SHOWN AVERAGED OVER 25 YEARS (1975-2000)
(EXCEPT 15 YEARS (1975-1990) FOR WORLD #6

Figure 7-8. Yearly Program Costs, Billions

A second conclusion stems from the absolute magnitudes of the costs of the program plans of Worlds #1 and through #6. It is to be noted (again assuming that the peak costs can be amortized into the total time period of this program), that the largest civilian space program which deploys every single system identified in the 1973 NASA Mission Model, every system concept identified as one of the initiatives in Volume III of this study, and other initiatives as well requires an average budget of less than $5 billion per year. This compares with an average budget for programs of about $3 billion per year today. It is seen, therefore, that contrary to first impressions, less than a two-fold increase in the funding for space would allow the fielding of every space program initiative and the entire mission model, yielding fantastic increases in performance in every functional area. Similarly, for the military, Worlds #4 and #5 represent the largest military budgets with the acquisition of the largest number of large and far-term systems (short of a catastrophic condition such as faced in World #6). For these worlds about $5 billion a year total budget compared to today's budget of about $2 billion will secure fantastic increases in performance in every functional category. Ten billion dollars a year average for both civil and military space would buy practically all systems identified by the military and by the civilian community and by the initiatives of this study, which is a noteworthy statement in itself. Of course, World #6 requires increased funding due to the imminent nuclear war.

Another way to view the program costs is that a continuation of the current military space budget of about $2 billion would allow response to world conditions represented somewhere between Worlds #1 and #4. For the case of the civilian programs, the current level of funding of about $3 billion, if continued for 25 years, would be adequate to meet the conditions of Worlds #1, #3, #5, and #6.

7.5 GENERAL SUPPORTING NEEDS

The supporting needs of each of the space programs developed in the previous section were extracted in each of the building block and technology categories illustrated in Figure 7-9. The supporting needs were divided into building blocks and technologies. The choices for low orbit transportation included an expendable booster of the Titan-III class, the Space Shuttle, and a large-lift vehicle of about five to ten times the lift capability of the shuttle. The choices for high orbit or transfer orbit transportations systems included the interim upper stage and the full capability tug (lumped into one category), a much larger tug with the option for a manned capsule front end, the 25 kW Solar Electric Propulsion System, a much larger Solar Electric stage perhaps five to ten times the ~~power level, and a nuclear stage for those orbital operations which require~~ extensive and frequent maneuvering. The orbital assembly and servicing stages, the support facilities, and the technologies required for support for the on-orbit operations, as well as the payloads themselves make up the remainder of the classes.

BUILDING BLOCKS	TECHNOLOGIES
LOW ORBIT TRANSPORTATION	Large Optics and Mirrors
Expendable Booster	Large RF Antennas
Shuttle	High Power/Energy Sources
Large Lift Vehicle (LLV)	High Power Radar
HIGH ORBIT/TRANSFER TRANSPORTATION	High Energy Lasers
IUS/TUG	Manned Orbital Assembly Techniques
Large/Manned Tug	Precise Pointing and Tracking
SEPS	LSI Computers/Processors
Large SEPS	CCD Focal Planes
Nuclear	Cryogenic Refrigerators
ORBITAL ASSEMBLY AND SERVICING STAGES	
Automated Servicing Unit	
Manned Servicing Unit	
Shuttle-Attached Manipulator	
Free-Flying Teleoperator	
ORBITAL SUPPORT FACILITIES	
Assembly and Maintenance Yard	
Warehouse	
Fabrication	
Research Laboratory	
Universal Test Satellite	

Figure 7-9. Building Block and Technology Categories

The number of mission opportunities for support of civilian programs peaks in World #2, while the corresponding number for the military peaks in World #4. A general picture of the maximum number of mission opportunities for each class of supporting building block can therefore be obtained by graphing the respective maximum number of mission opportunities, resulting in the graph of Figure 7-10. Note that these represent mission opportunities, not a traffic model, and that the missions include all initiatives in this report as well as most of the systems described in the 1973 NASA STS Mission Model and the 1974 DoD STS Mission Model. Furthermore, there exists a degree of redundancy, since some functionally similar mission could be performed by the same space system, yet were treated as separate missions in the additions leading to this graph.

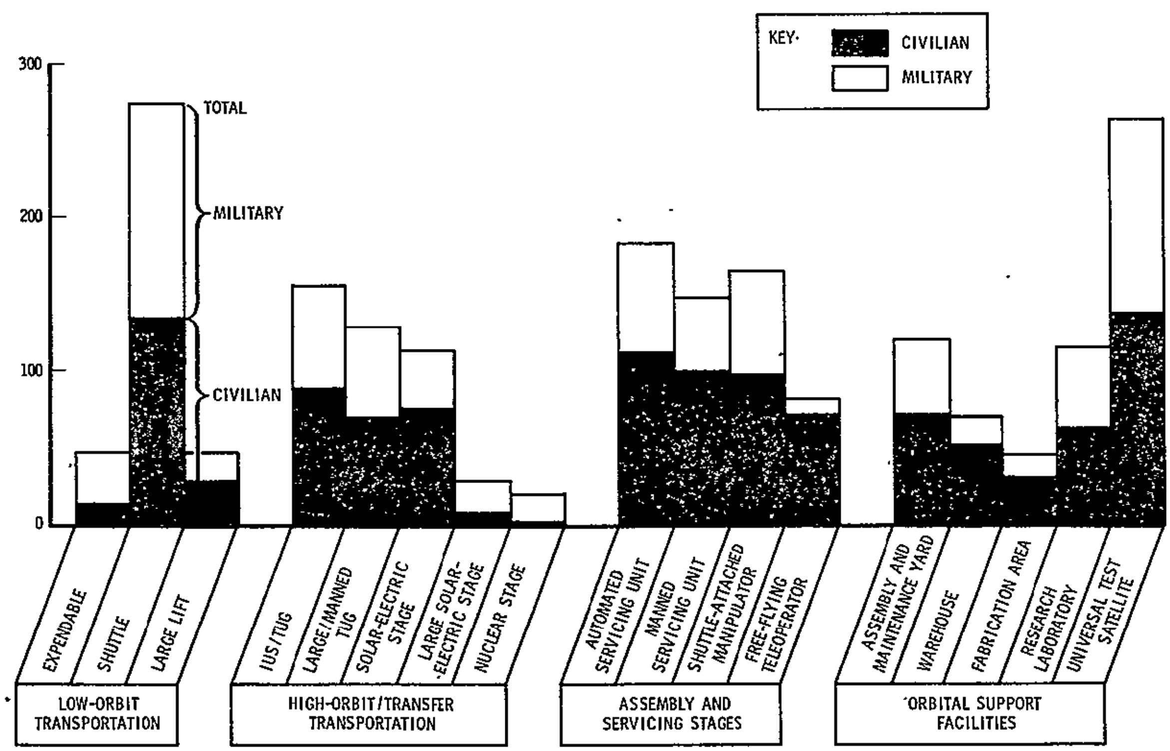


Figure 7-10. Number of Mission Opportunities for Transportation and Support

The maximum number of mission opportunities yields several key messages:

1. The shuttle is a highly useful and versatile booster.
2. Though there are foreseen several needs for expendable boosters and vehicles of larger lift than the shuttle, those needs are only about 10 percent of the needs for the shuttle (though since the priority of all missions is considered of equal weight in this graph, the conclusion cannot be reached from this data alone that there is little need for boosters other than the shuttle).
3. The need for orbital transfer transportation vehicles is about half of that into low orbit, i.e., about half of the systems require an upper stage boost.
4. The IUS and Tug can satisfy about half of the upper stage needs.
5. ~~There is a strong call for a solar-electric stage, particularly~~ for civilian missions, and an equally strong call for a large/manned tug. An upper stage much larger than the 25 kW Solar Electric stage is required in only a few system (see caveat in Point #2).
6. Assembly and servicing stages of some kind are needed for about half of the missions. The choice of manned versus unmanned, and attached versus freeflying teleoperator cannot be made on a gross basis, but requires detail examination of the roles of each mission.
7. Orbital support facilities such as assembly and maintenance "yard" and research laboratories are needed in about of the missions, with flexible test satellites being useful in most.

A similar treatment of the general techniques and technologies required for the set of initiatives as a whole was made, with the results plotted in the graphs of Figure 7-11.

The specific technology needs of the initiatives taken as a group without any weight given to type, application, or function, are shown in this graph, with each dot representing the requirements of a given initiative.

The dashed lines for each vertical graph represents today's approximate state of the art of the technology. It is seen that optical

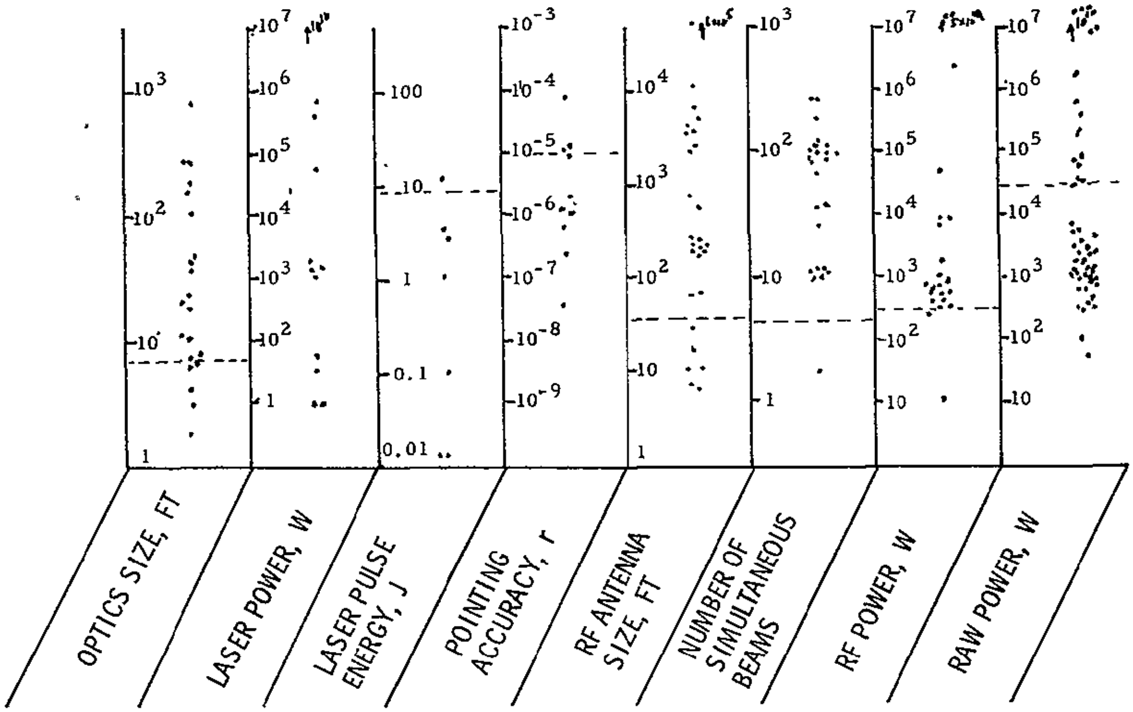


Figure 7-11. Summary of Technology Needs

sizes called for are generally much larger than those supported today. Pulsed laser energy state of the art is entirely adequate, provided the lasers are space qualified, and pointing accuracy demonstrated is adequate for many of the applications, though some require 1-2 orders of magnitude improvement.

RF antennas are required in very much larger sizes than that supported today. This is also true of the number of simultaneous beams generated in an RF antenna, although the number of beams called for does not represent a great increase in the technology, it simply has not yet been done in space. The RF transmitted power required in almost every case is higher than that demonstrated to date, although in only a few cases does it require new technology since it can be achieved by paralleling devices fairly well understood today. Many of the raw power requirements are below those which have been demonstrated in Skylab to date, although in a few cases, such as in energy delivery, clearly much more power is required. This is also true of some of the high power observation devices in orbit where raw power in the order of a few hundred thousand to a million watts is required.

This graph renders a feeling for the direction of the technology developments which are needed to accommodate the group of initiatives as a whole. It does not reflect the worth of any initiative or group of initiatives over any other.

Specific insight can be obtained by referring to Figure 7-12 in which the needs and status of technology are related for several specific initiatives.

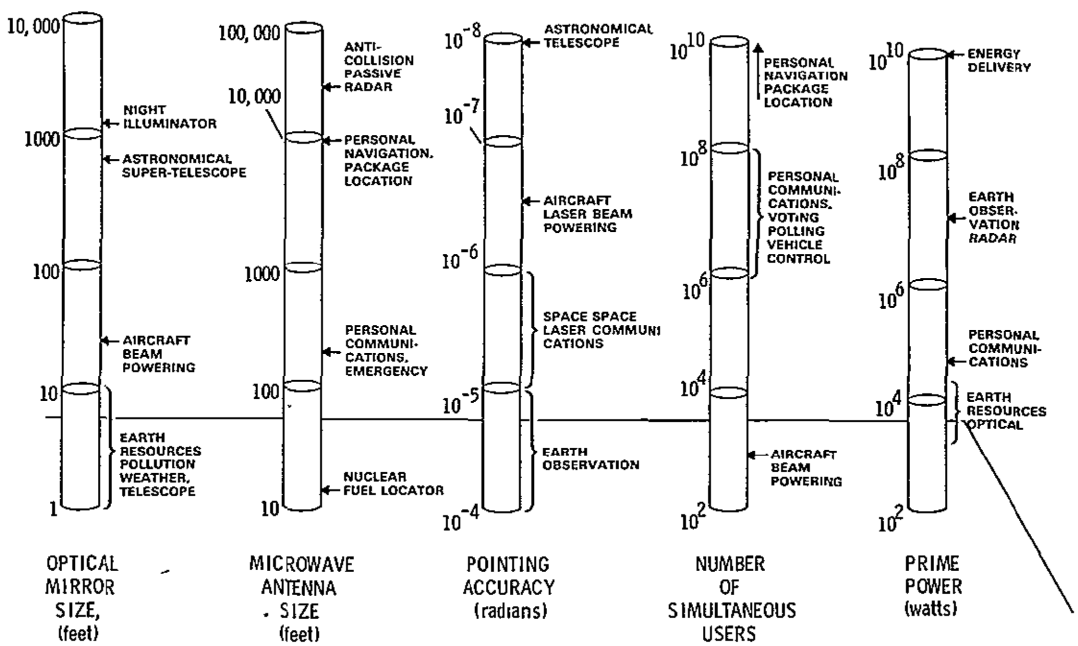


Figure 7-12. Summary of Technology Needs

The support functions required, and their implications, are illustrated in Figure 7-13. Further, the data of this section indicates

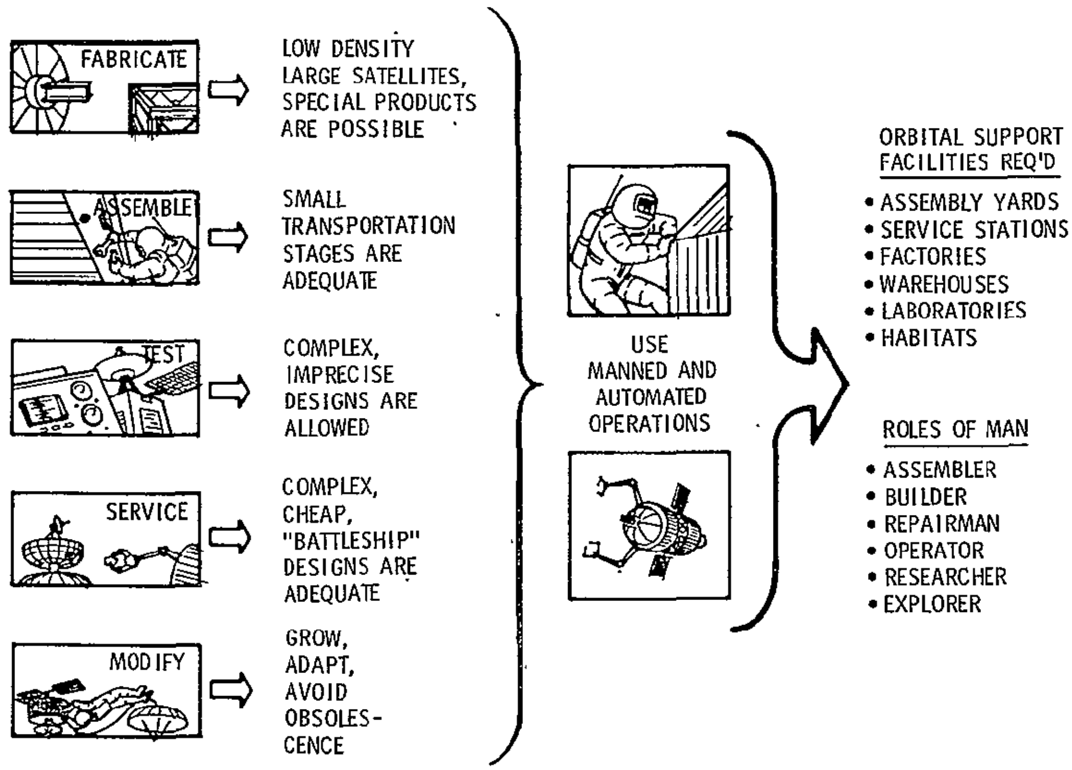


Figure 7-13. Guiding Principles for Support Functions

that the role for man in space will probably shift from the early exploratory roles to that of builder, operator and repairman, as well as that of researcher. Since about half of the missions require some form of assembly, initialization, servicing and reconfiguration in space, man is seen emerging as an element in providing the support functions for "care and feeding" of mission-oriented satellites, and in providing and operating the orbital bases and facilities for such operations. These changing roles of man are illustrated in Figure 7-14.

7.6 SPECIFIC SUPPORT NEEDS

The needs for supporting building blocks under the different conditions which will exist for each of the six alternate world scenarios were collected and are presented in the following data.

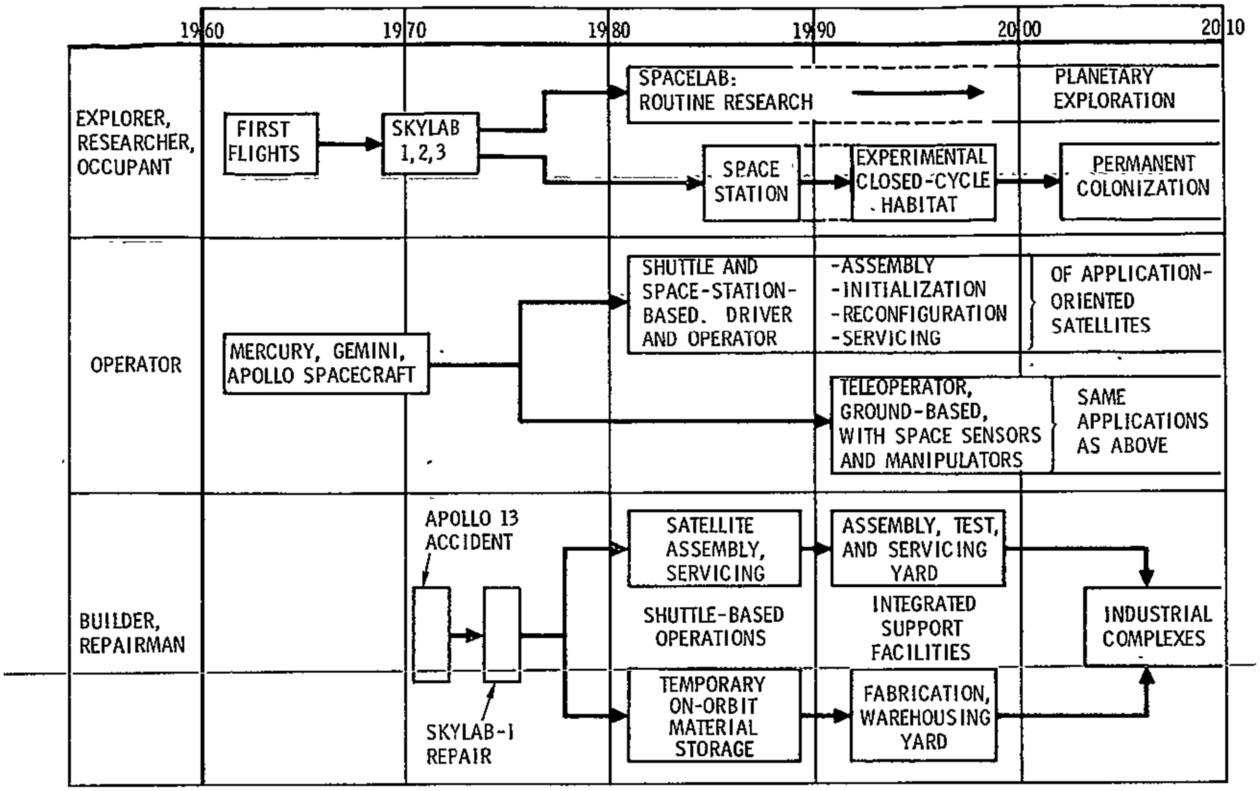


Figure 7-14. Roles of Man in the Space Program

7.6.1 Low-Orbit Transportation

The first category of support "building block" needs discussed pertains to transportation into low earth orbit, the data for which is shown in Figure 7-15.

The sum of all the civilian and military missions (initiatives) in which there are opportunities for utilization of each class of booster is shown as a function of the world number for the alternate scenarios. These were developed by summing the support needs of each initiative called for in each program plan. The format for presentation was chosen as straight lines connecting the data points for each of the world numbers, even though it is recognized that the data only exists for each discrete world number, since the connecting lines are useful for pictorial representation and for trend extrapolation. This graph as well as the following ones are plotted for the combination of both civilian and military opportunities and for the entire time frame from 1980 to the year 2000, i.e.,

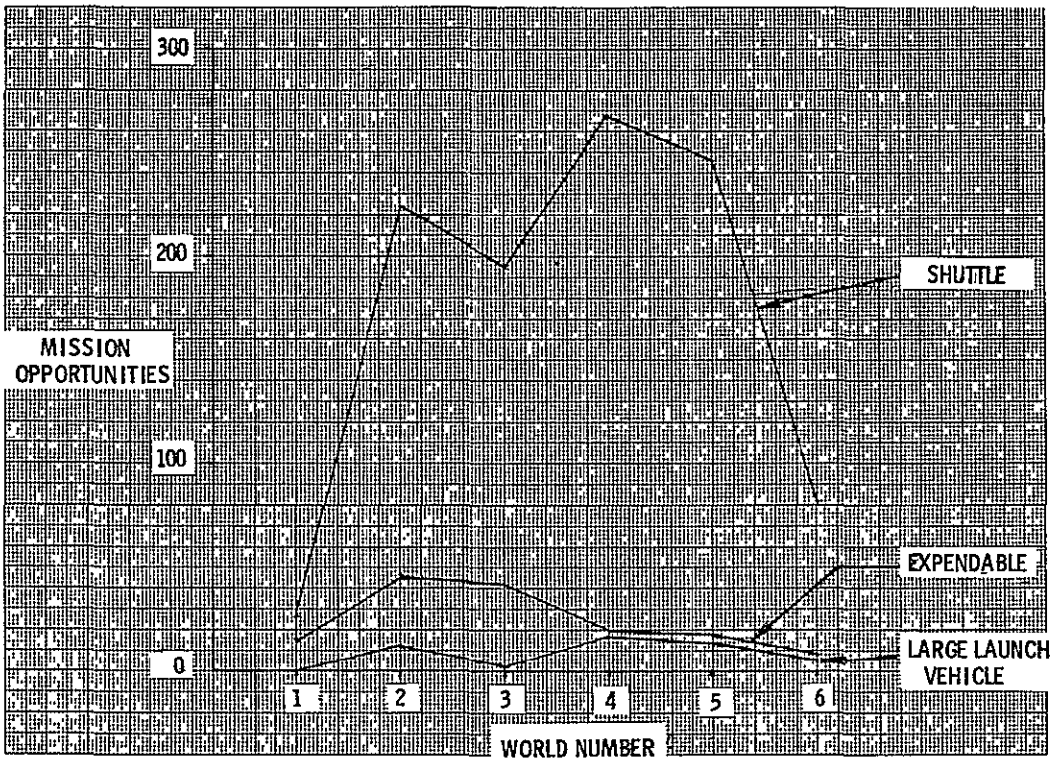


Figure 7-15. Mission Opportunities for Low Earth Orbit Transportation

incorporating the near-term, midterm, and far-term program opportunities. It is to be emphasized that this graph as well as the following ones represents mission opportunities, rather than a traffic model, the number of flights required of each booster (for instance) being far greater than the number of mission opportunities for its use.

A cursory analysis of the data on Figure 7-15 indicates that the shuttle is a versatile, high demand booster and will continue to be so through the end of the century, compared to an expendable or a larger launch vehicle, and continues to be very much in demand regardless of the nature of the future world facing us within the choices of the alternate world scenarios. The opportunities for utilization of the shuttle are many and relatively constant for Worlds #2 through #5 inclusive, being far smaller for World #1 and for World #6, which is to be expected since Worlds #2 through #5 are more moderate views of the future calling for greater numbers of space systems. World #1 is a very austere world for the military and civilians, results in a small number of payloads, and therefore opportunities, for any booster. In World #6 the civilian opportunities drop off dramatically, most of the opportunities shown being for military operations facing up to the war in 1990. The ground rule for requirements for a larger lift vehicle than the shuttle was established rather arbitrarily in the early part of the study in the following way: if a particular space program or initiative required more than about 100 shuttle flights to establish the system, a larger lift vehicle was indicated; otherwise the shuttle was deemed an adequate booster.

Data such as presented in Figure 7-15 cannot be used by itself to make a case for not developing a large lift vehicle or for phasing out expendable boosters, because the nature of the programs requiring such boosters and their relative priorities must also be addressed. It is clear from this chart, however, that the shuttle is an extremely versatile, high demand, well thought out program of great utility, even though many of the payloads which are assumed flown in the future worlds were not conceived at the time the shuttle design was definitized.

7.6.2 Orbit Transfer Transportation

The second category of support building block needs pertain to orbit transfer transportation, the data for which is shown in Figure 7-16.

This graph indicates that the IUS and Full Capability Tug are desirable developments for which the demand exceeds all other high orbit transfer transportation devices for most of the worlds considered. The IUS and FCT were lumped into one class of vehicle under the assumption that either both would be available during the greater portion of the rest of the century, or that some single vehicle of similar capability would be.

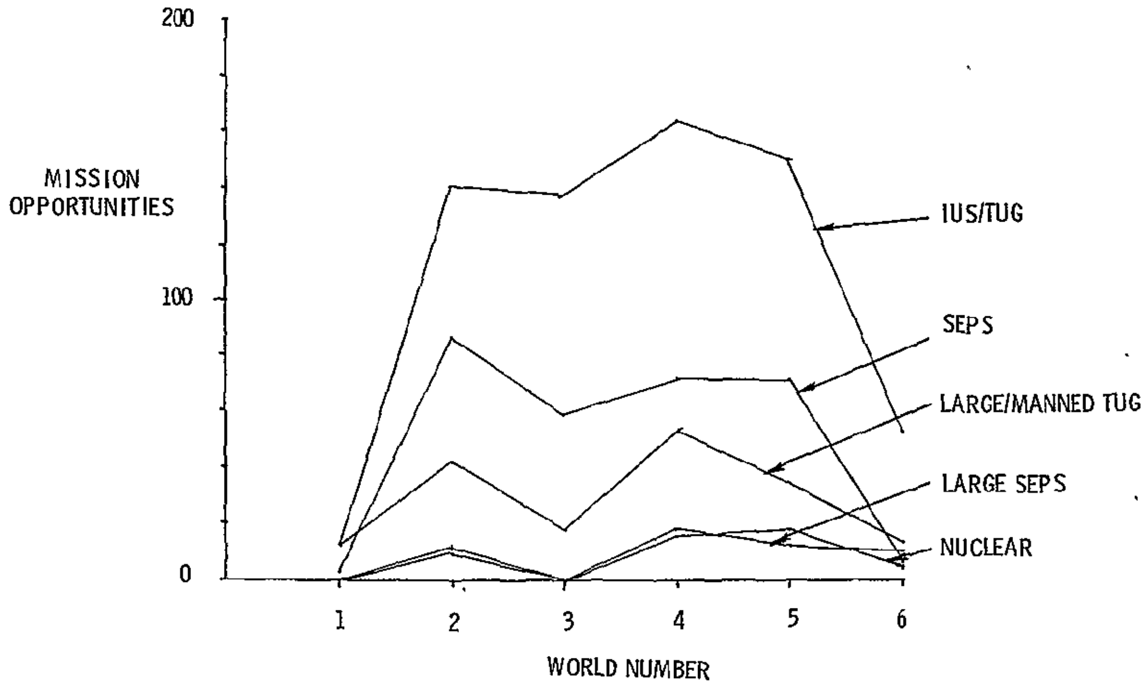


Figure 7-16. Mission Opportunities for High Orbit/Transfer Transportation

the 25 kW Solar Electric Propulsion Stage is next, with a larger version of the tug with a manned front end being next in line. The same trend is evident as for the low orbit transportation case: that most of the more moderate versions of the future world tend to have a relatively constant call for space supporting vehicles, with a small call in World #1 reflecting the austere view of the world domestically and with World #6 reflecting primarily a military call for near-term space systems. The total number of opportunities for an upper stage of some sort are about half of those requiring low altitude boost. The number of missions in which any particular upper stage is required is somewhat smaller than the number of opportunities shown, since a fair number of mission requirements can be met by a choice of several upper stage options, and all possible candidates contributed to the mission opportunities.

7.6.3 Orbital Assembly and Servicing

The third category of support building block needs pertain to orbital assembly and servicing stages, the data for which is shown in Figure 7-17.

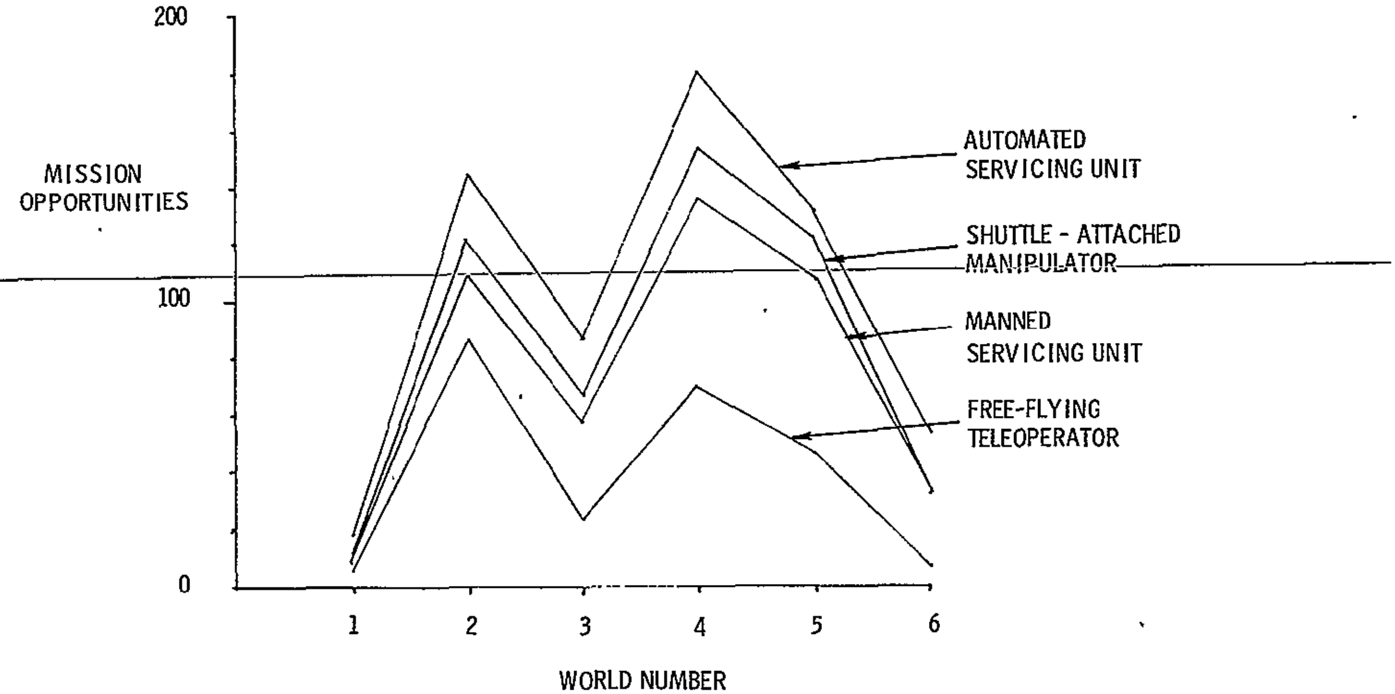


Figure 7-17. Mission Opportunities for Orbital Assembly and Servicing Stages

A similar trend is evident in this as well as in the following graphs where the number of mission opportunities for orbital assembly and servicing stages is seen to peak in the moderate worlds. A characteristic not evident to the degree in previous graphs, however, is the peaking of the demand for these stages in Worlds #2 and #4. The reason for this peaking is that World #4 has the largest number of mission opportunities for the military community, and the accentuation of the peaks compared to World #3 is due to the greater percentage of large, heavy missions in Worlds #2 and #4 which require some form of orbital assembly and servicing. It is also seen that a fairly large number of mission opportunities exist for assembly and servicing units of some type independent of what the future will actually turn out to be. The ground rule used for specifying automated versus manual units was that no choice was made unless the mission clearly required man or clearly had to be unmanned (such as a flight in the radiation belts). Thus, the manned opportunities nearly equal the unmanned ones, the choice being left to those who might wish to develop specific initiatives further.

7.6.4 Orbital Support Facilities

The fourth category of support building block needs pertain to orbital support facilities, the data for which is shown in Figure 7-18.

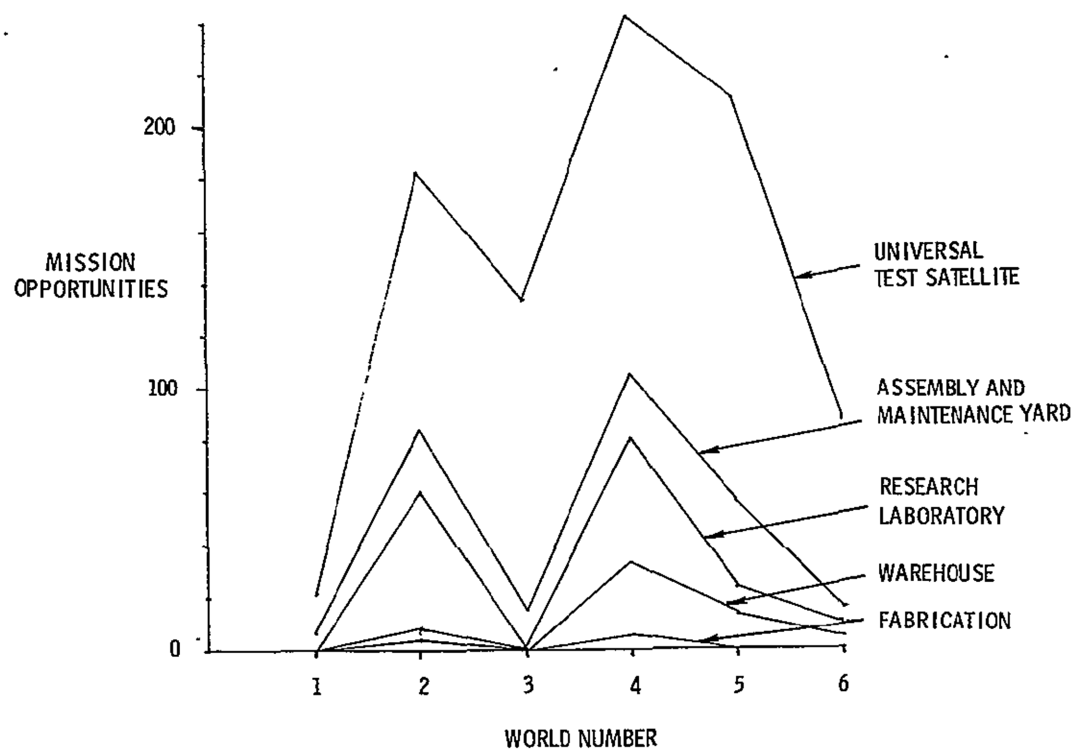


Figure 7-18. Mission Opportunities for Orbital Support Facilities

In this graph it is seen that a very large number of mission opportunities exist for a universal test satellite, which might be represented by a small satellite vehicle used in conjunction with the shuttle or used in a sortie mode in the process of development of satellites. This could be considered an outgrowth of the current "Space Test Program" of the DoD, which is used as a testbed for a variety of experiments, with the experimenters not bearing full charges for the booster or payload integration. Assembly and maintenance yards are a generic term which is used to describe functionally-oriented space stations. These are required in Worlds #2 and #4 in particular, as in a research laboratory of some sort, be it a Spacelab or a much larger free-flying laboratory such as some concepts of research-oriented space station. Fabrication and warehousing are similar functions that, although representing larger satellites, are needed for fewer initiatives. The same trend is evident in the needs for these functions in the other worlds, with the smallest call being for Worlds #1 and #3. Though there may well be a need for "space stations" as research tools to determine the utility of man, to perform general research, and to determine his limits, the present work only addresses the needs for facilities to support the initiative system concepts. Thus, the term "space station" is not used herein, though functionally the above classes of space vehicles may be identical with some versions of such stations, and they may be called upon to perform similar functions. This is particularly true if the supporting functions require manned operations.

7.6.5 Orbital Techniques and Technology

The fifth category of support building block needs pertains to techniques and technologies, the data for which is shown in two parts. The first part is in Figure 7-19.

The technologies and techniques most in demand are large RF antenna structures and assemblies, with assembly and initialization done in

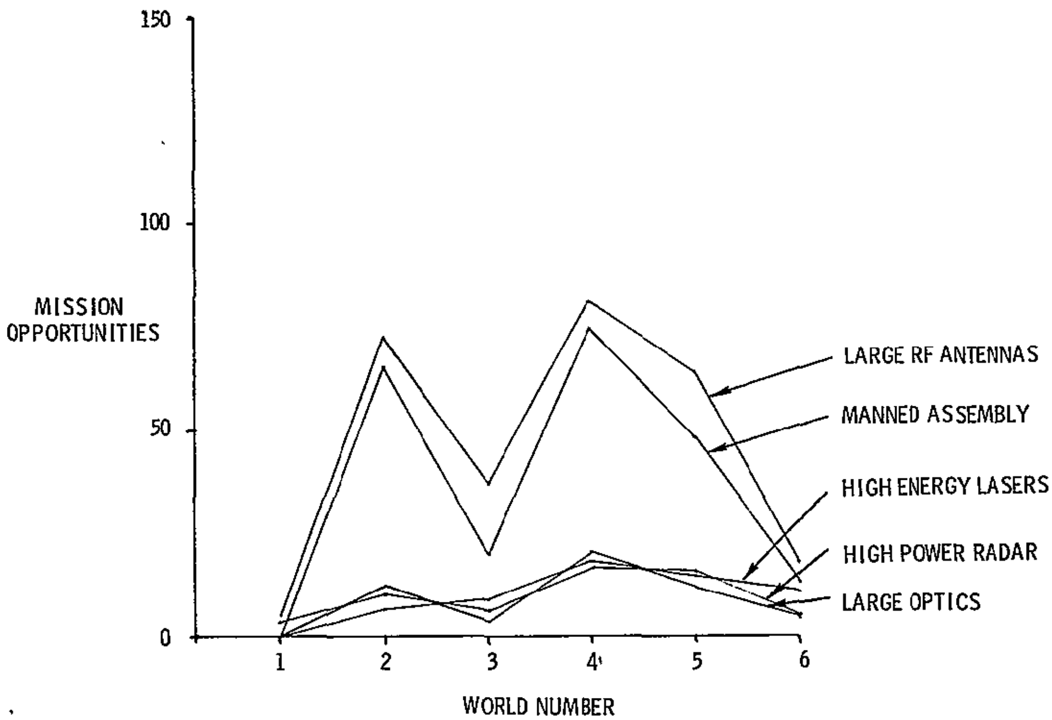


Figure 7-19. Mission Opportunities for Orbital Techniques and Technology

space. This is true for all intermediate worlds as was the case for the previous four charts. The term "large antennas" includes monolithic structures and the concept of stationkept sub-arrays. The functions of man include assembly, orientation, functional "tweaking," initialization, and repair.

High energy lasers, high power radar, and large optics have a considerably smaller calling although it tends to be fairly constant for the inbetween worlds. The smaller number of opportunities for optics, lasers, and high power radar reflect the smaller number of initiatives in observation compared to communications, though this disparity actually reflects mainly study team limitations in time and resources rather than a priority emphasis. No such priority was intended.

The second part of the technology data is shown in Figure 7-20.

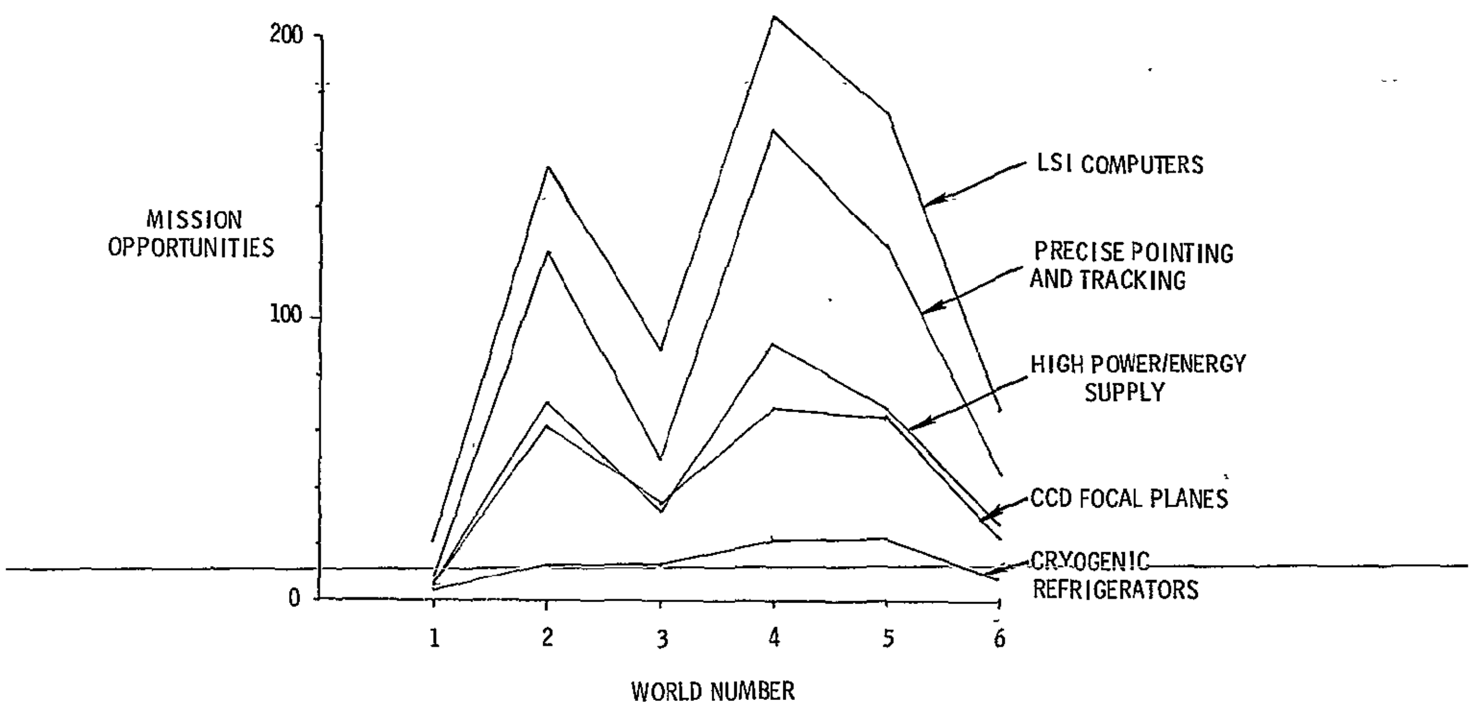


Figure 7-20. Mission Opportunities for Orbital Techniques and Technology

This is a continuation of the subject of the previous graph in which large-scale integration of microelectronics and computers, precise pointing and tracking of optical or microwave devices, high power/energy prime and transformed sources, and charge-coupled devices are seen to have great calling in all of the intermediate worlds, and reasonably large calling in World #6. Cryogenic refrigerators to support long-wave infrared operations in space are seen to have a small but constant demand in most of the worlds considered.

The peaking in Worlds #2 and #4 again reflects the large number of big, complex systems fielded in these worlds, with their resultant need for microelectronics, pointing of large apertures, and high power needs. Significantly, however, a minimum need exists regardless of the world condition. Thus it is seen that most of the supporting building blocks and technology are primarily required in the more moderate views of the future world.

COMMON NASA DOD
SUPPORT NEEDS

8. COMMON NASA/DOD SUPPORT NEEDS

The extraction of needs for supporting building blocks and technology which are shared by the civilian and military space communities follows readily from the data used to prepare the general and specific support requirements presented in Section 7.

8.1 DEFINITION OF COMMONALITY

The definition of commonality used in this study is derived with reference to Figure 8-1.

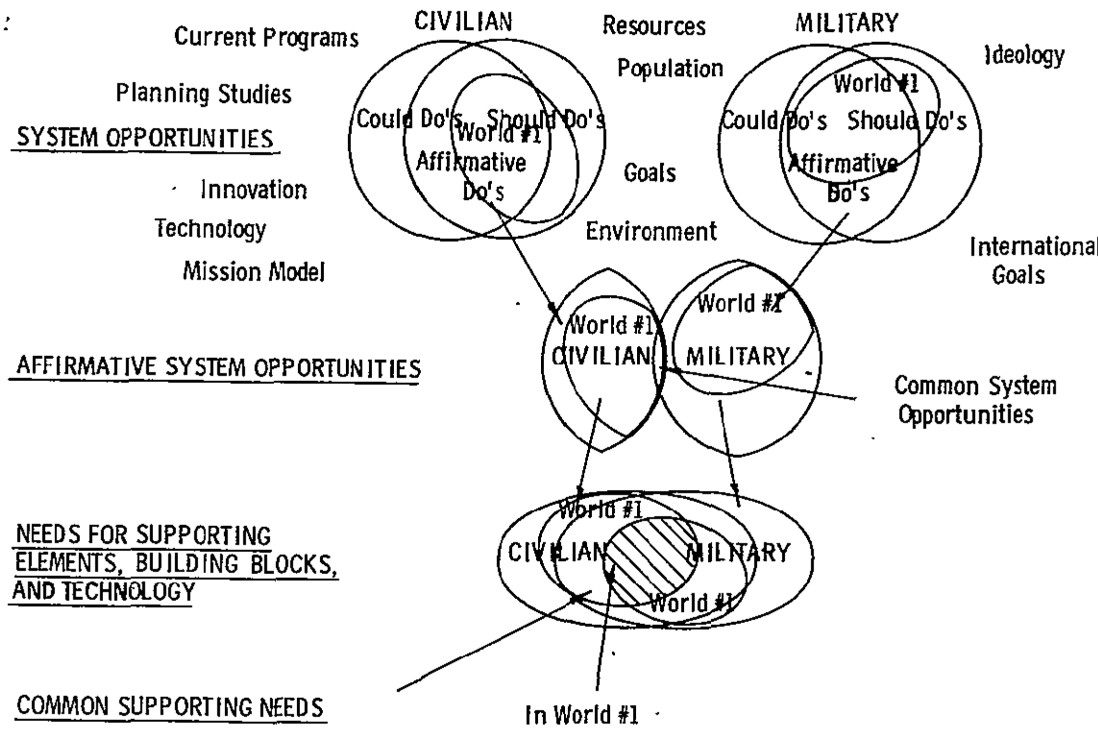


Figure 8-1. Commonality Study Process

The system opportunities were selected (in Volume III) for both civilian and military opportunities in the following way: one set of lists was prepared from those initiative opportunities which technology might support in the next 25 years, regardless of any accepted need for the capabilities. These are entitled the "could do's." Simultaneously, the functions which would be needed in the future environments are listed as "should do's" in the graph regardless of the status of technology to support them. The intersection of the "could do's" and the "should do's" we call the "affirmative do's," which are the system opportunities that are not only feasible but are needed and called for in the worlds of the future. The affirmative system opportunities for the civilian and for the military communities were prepared independently using this process, and they generally represent separate and distinct initiative systems, although in some cases the same system could perform dual functions.

The primary output of this study is a common need for the supporting building blocks and technologies under various world conditions. This common need is developed from the needs of the military and civilian affirmative system opportunities. The intersection of the supporting needs is therefore shown as the common supporting needs. Particular definitions of the future world, such as indicated by the ellipses and resulting curves on Figure 8-1, will result in a particular set of common supporting needs. There may well be sets of building blocks and technologies which will support all world in common (at least as defined in this work), and if such common sets exist, a powerful case could be made for their development.

The following graphs present the common NASA/DoD supporting needs for building blocks and technologies defined for each of the alternate world scenarios considered in this study. While it is recognized that this is not the only way to derive or present commonality data, it was chosen for this study as being realizable within the time and resources available, and having a high probability of yielding meaningful results with minimum dependence on subjective assumptions.

The graph on Figure 8-2 illustrates the derivative of the commonality data for a particular example, i.e., for the space shuttle. The data

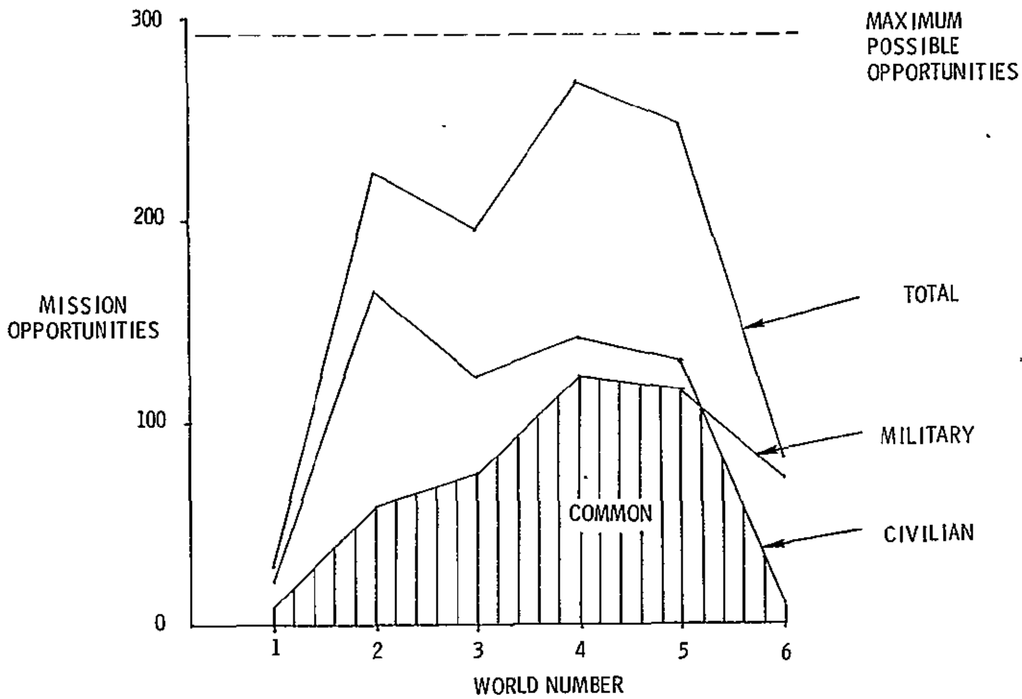


Figure 8-2. Mission Opportunities for the Space Shuttle

on space shuttle mission opportunities as a function of world number is reproduced from Figure 7-12 and labeled the "total curve" - a summation of the military and civilian mission opportunity components. These components add up to the total curve. The maximum possible mission opportunities for the shuttle is also shown, defined as the opportunities for civilian employment of the shuttle in World #2 added to the opportunities for shuttle utilization for the military in World #4. The maximum is therefore a specific measure in which all mission opportunities identified are utilized, and represents a synthetic world not identified specifically. The common needs for the shuttle are defined as being the smaller of the military and civilian components. By way of example, for World #3 there are 73 mission opportunities for military application of the shuttle and 142 opportunities for civilian application. A common utilization of the shuttle exists for 73 mission applications. Therefore, that area lying underneath the lower of the military and civilian curves is by definition the number of common mission opportunities for the space shuttle, and is to be measured against the 100 percent commonality curve, defined as one-half of the total opportunities. (If the military and civilian opportunities are equal, the same number supports both.)

Analyzing the graph, we find that the common needs for the space shuttle peak in Worlds #4 and #5 approaching 100 percent, and drop off on both extremes of worlds to a somewhat smaller number. The commonality still exceeds 25 percent, however, for all worlds including the catastrophic World #6. Thus, there are common requirements or mission opportunities for the space shuttle regardless of the exact nature of the future. For all the more reasonable or moderate views of the future ~~represented by Worlds #2 through #5, the commonality exceeds 50 percent.~~ The statement can therefore be made that the shuttle is a booster having very high common use between the NASA and the DoD in most views of the future examined in this study.

The number of mission opportunities in common between NASA and DoD for each world number for each specific building block and technology item have been plotted and will be found in Volume IV in the same format as the example of the space shuttle discussed above.

8.2 COMMON SUPPORT NEEDS

In the graph of Figure 8-3 and following graphs the results of the commonality investigation are summarized for ready interpretation of building block and technology needs. The data plotted in these graphs are the common needs for each class expressed as a percent of the maximum possible commonality. Reviewing the data of Figure 8-2, we see that if the military and civilian mission opportunities for a vehicle were equal and one-half of the total, and if the total opportunities were equal to the maximum possible, that the common opportunities would be one-half of the maximum possible and could be written as 50 percent. For normalization

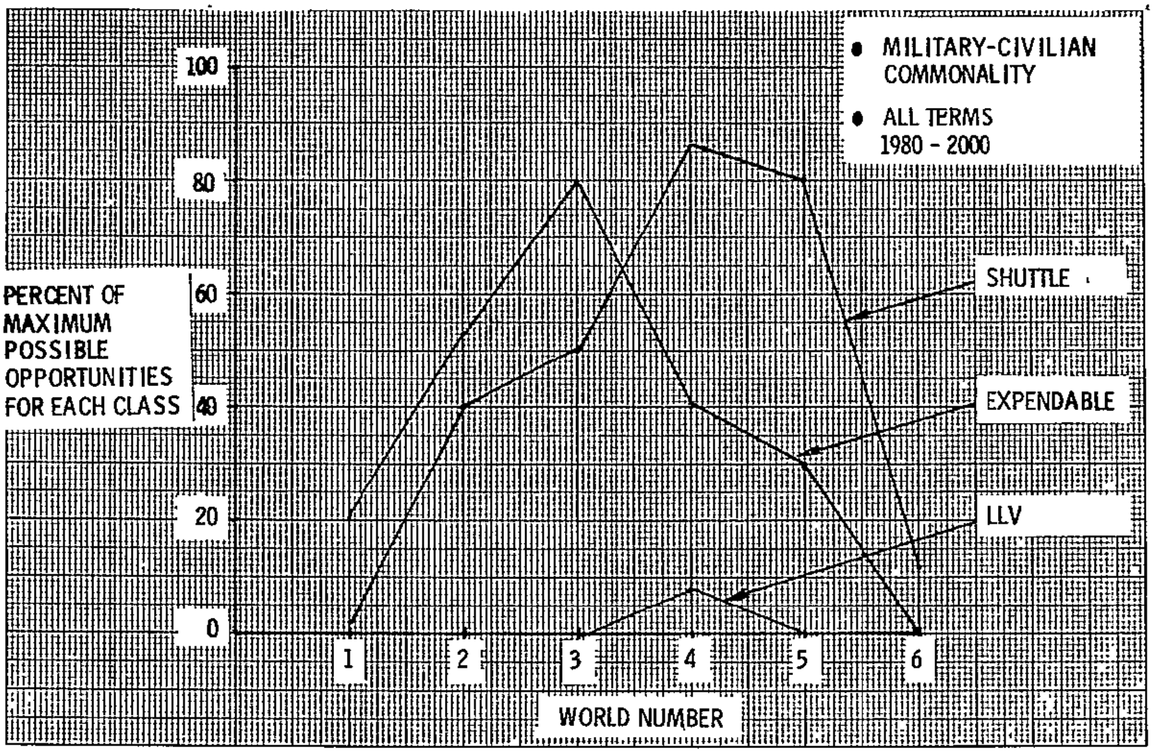


Figure 8-3. Common Needs for Low Earth Orbit Transportation

purposes, however, the commonality will be defined as twice the common needs divided by the maximum possible needs and expressed as percentage. Thus, in the figure, it is seen that the shuttle common needs in World #4 are about 80 percent of the maximum possible needs. Thus, the commonality is expressed as a percentage of the maximum possible opportunities in the following graphs, whereas it was shown as the absolute number of common opportunities in the preceding graphs.

It is seen from Figure 8-3 that the commonality of the shuttle is high for Worlds #3, #4, and #5 and fairly high for Worlds #2 through #5, which are all the reasonable worlds. This is also the case for the expendable boosters. It is seen that the large lift vehicle has few common opportunities, as well as only a few percent common needs (and then only in World #4) with common needs being non-existent for any other world. This is because the large lift vehicle is only required for large far-term systems which are required primarily in World #2 by the civilian and in World #4 by the military, but only simultaneously in World #4. We can conclude that the shuttle, as well as any expendables which may be needed, possess a high degree of commonality, whereas the large lift vehicle does not. This conclusion must be tempered with the statement that the launch vehicle requirements for the orbital support facilities themselves were not examined, and could well change the above conclusions. Furthermore, it must be remembered that even though the absolute and common opportunities for a given device might be small, those missions could be judged extremely important, increasing the hazard of writing off any vehicle with small showing in these results.

In Figure 8-4 the commonality curves are shown for high orbit and transfer transportation. It is seen that for all the reasonable worlds the IUS and tug have a large degree of commonality, followed very closely by the 25 kW Solar Electric Propulsion Stage, and by a large or manned version of the tug. This is particularly true for Worlds #3, #4, and #5.

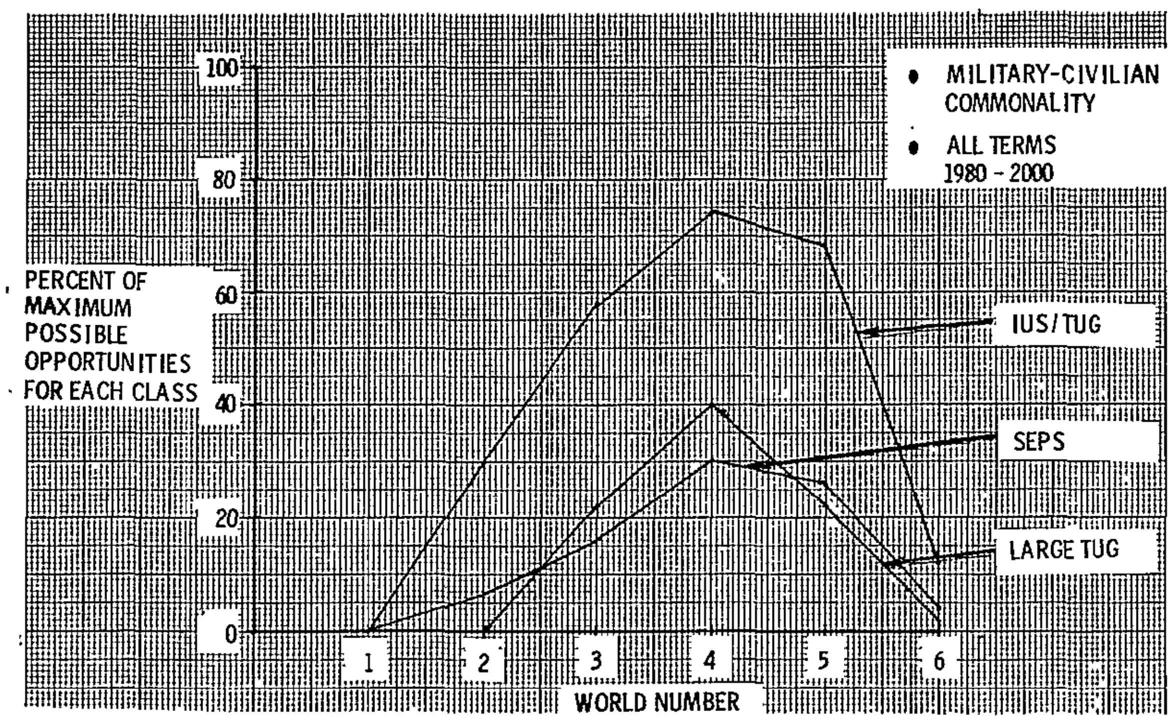


Figure 8-4. Common Needs for High Orbit/Transfer Transportation

Some common needs also exist in World #6, but none in World #1. Again this result follows inherently from the definitions of the scenarios of those worlds. It is to be noticed that there are no common needs for the nuclear stage since most needs for such a stage appear to stem from military requirements for prolonged or continuous maneuvering on orbit. (Civilian exploration of the Solar System and beyond was only very lightly treated in this study, and the latter conclusion could well be reversed upon its incorporation.)

The graph on Figure 8-5 shows the common needs for assembly and servicing stages. The same trend is evident as for the transportation vehicles, with common needs being high for the automated and manned servicing units, as well as for the shuttle-attached manipulator (which is now a part of the baseline shuttle). These needs are high for the intermediate worlds. A free-flying teleoperator was also defined and is shown to have fewer possible common opportunities (though an automated assembly, servicing, and warehouse facility might rely extensively on such capability).

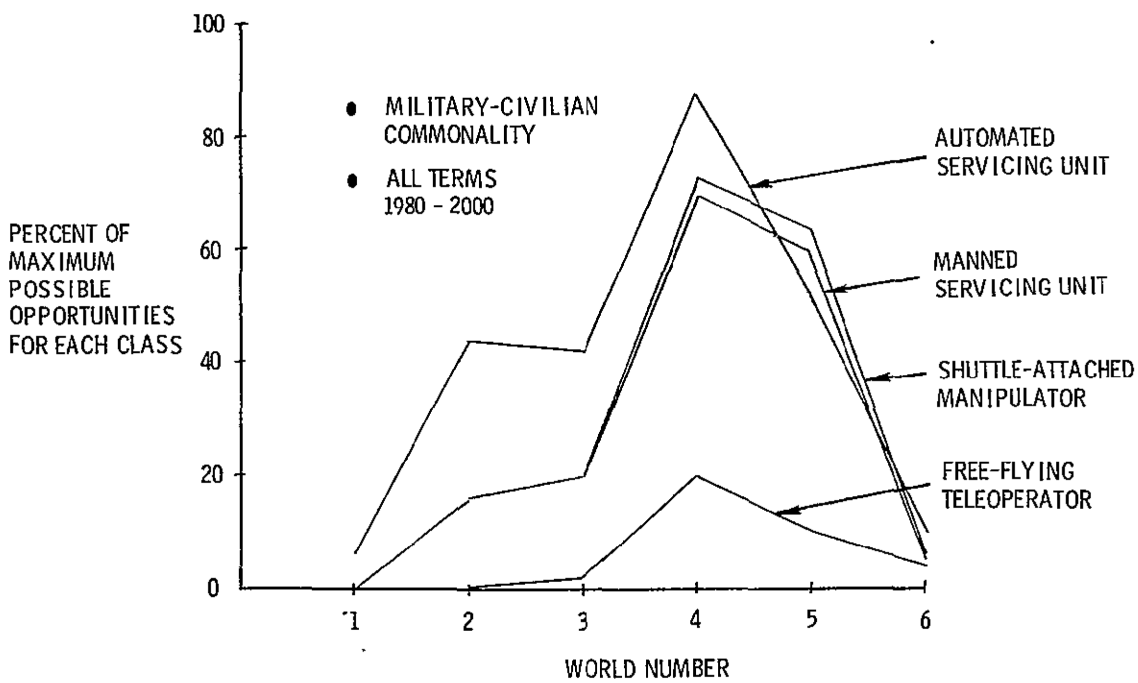


Figure 8-5. Common Needs for Assembly and Servicing Stages

The data on automated and/or manual assembly and servicing units makes a good case for developing such capability based on common NASA/DoD needs, quite aside from utility considerations pertaining to any one particular system-application.

Common needs for orbital support facilities are shown on the graph on Figure 8-6. It is seen that a universal test satellite (free-flying test laboratory) has a very high commonality in most of the reasonable worlds, with assembly and maintenance facilities having high commonality primarily in Worlds #4 and #5, although having some degree of commonality also in Worlds #2 and #3. Warehousing, fabrication, and research laboratories do not possess commonality in Worlds #1, #2, and #6. In particular, warehousing and fabrication is only shown to have commonality in World #4.

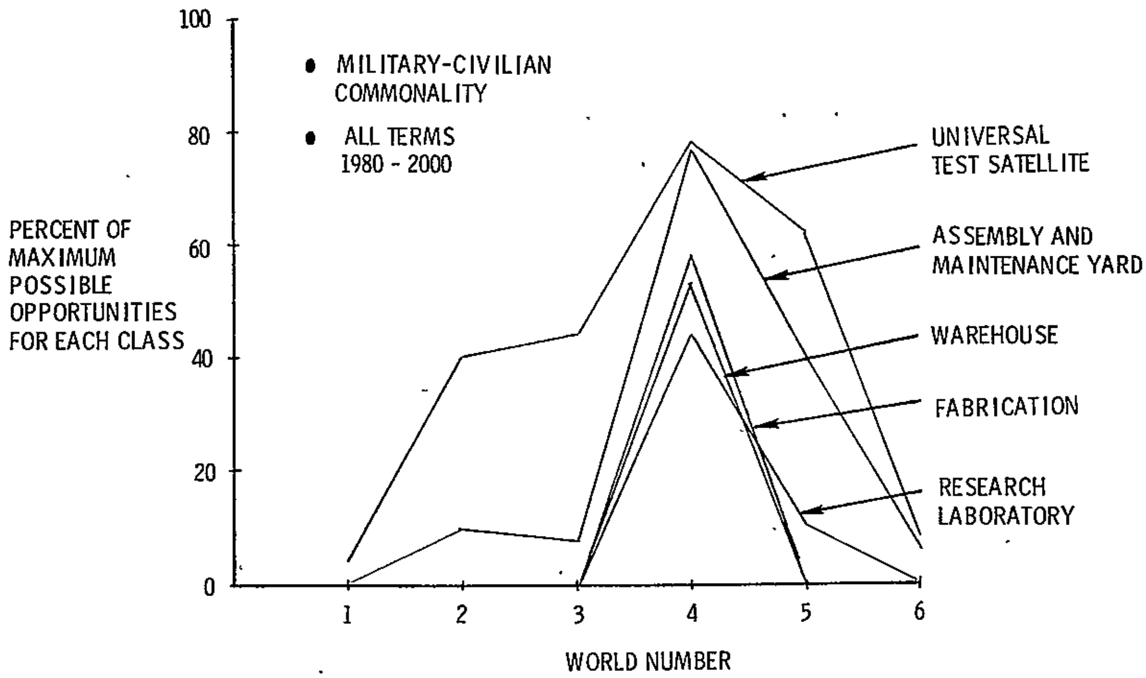


Figure 8-6. Common Needs for Orbital Support Facilities

Thus, common need for orbital support facilities is very high in World #4 as expected. These support facilities could be manned, automated, or telefactor operated, as no distinction is made in this study. Again, by proper definition of the components of such facilities, some of the above conclusions could be modified.

Common needs for orbital technology are shown on the graphs of Figure 8-7 and the following figure. It is seen that large RF/microwave antennas and high power radar have the highest degree of commonality for all worlds, whereas large optics and high energy lasers possess a high degree of commonality only in Worlds #5 and #6, with a minor peak in the relatively benign World #2. World #3 has no common requirements for lasers or large optics, nor does World #1. The low commonality for high energy lasers is to be expected, since they find few civilian applications other than powering of aircraft. The communications and radar applications, however, find missions in both civilian observation of surface features and aircraft tracking and in military equivalents, resulting in a fair degree of commonality.

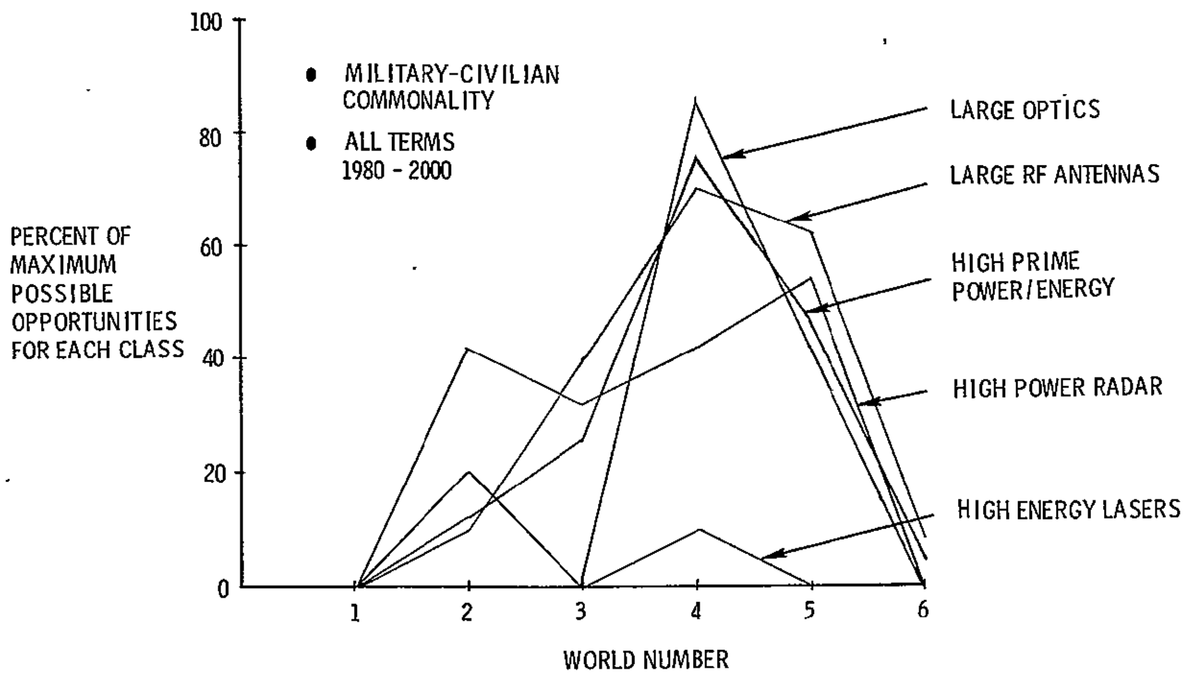


Figure 8-7. Common Needs for Orbital Technology

The remainder of the common requirements for orbital techniques and technology are summarized in Figure 8-8. It is seen that the same trend applies as for the previous graph with all of the technologies having a common need peaking in Worlds #3, #4, and #5, with a reduction in needs for the more extreme worlds. It is noteworthy that space assembly has 100 percent common application in World #4, and would make a case for such capability were it not for the small absolute number of opportunities in which it was identified. That may reflect incomplete treatment of the topic by the study team more than any judgment on the topic.

Common needs for each building block and technology are also plotted as a function of time, and will be found in Volume IV. In general, the needs are fairly flat with time.

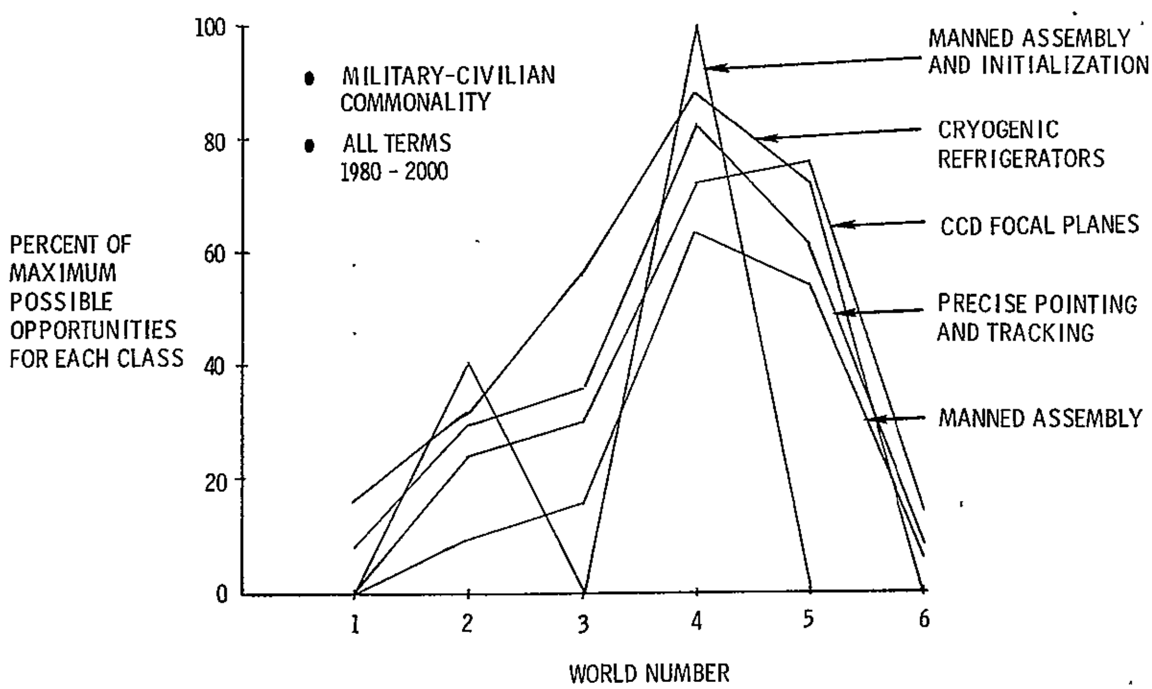


Figure 8-8. Common Needs for Orbital Techniques and Technology

A general feeling for common support needs emerges with reference to Figure 8-9 in which are plotted the percent of common needs for each building block in the best of the "reasonable" worlds (#2 to #5), and for the best of the "extreme" worlds (#1 and #6). It is seen that most building blocks possess an extremely high degree of commonality in most of the reasonable worlds, but fairly little for all the worlds, though many categories are definitely non-zero. Depending on the importance of the specific missions requiring support in all worlds, a good case may or may not be constructed for development of more supporting elements. Certainly a powerful case can be constructed for all the "reasonable" worlds.

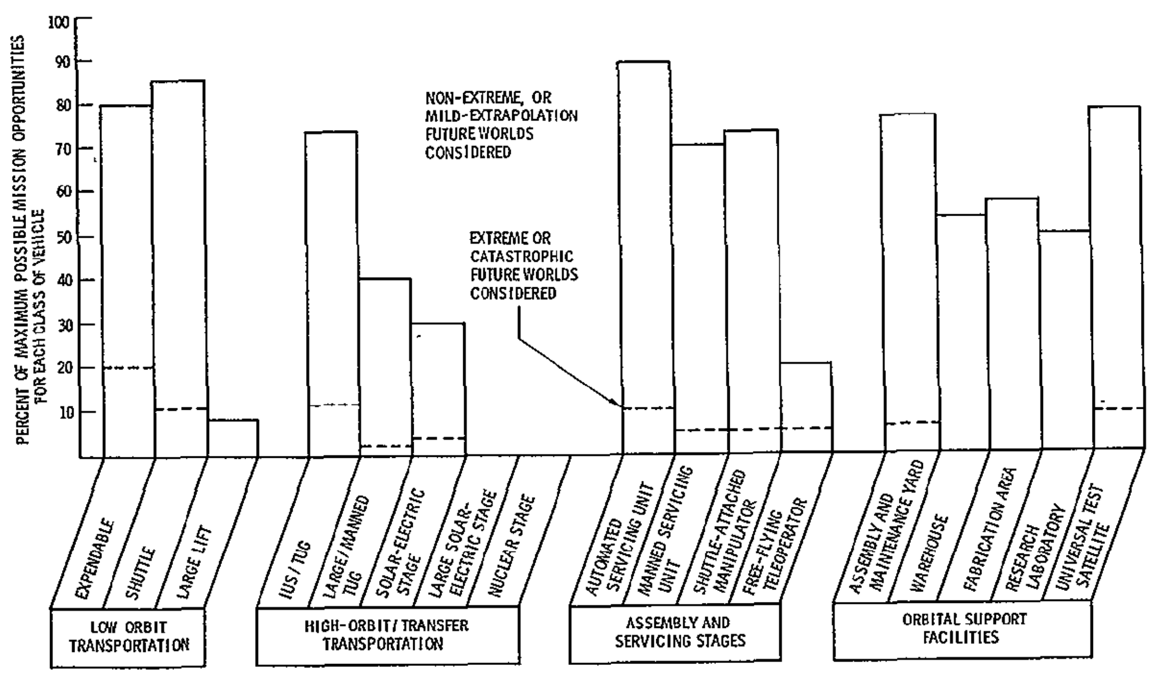


Figure 8-9. Common NASA-DoD Needs for Transportation and Support (1980-2000)

9. DEVELOPMENT PLANS

The previous section presented results of the study in terms of common needs for NASA and DoD supporting elements, building blocks, and technologies for the conditions of six alternate world scenarios assumed for the purpose of this study. Various conclusions and insights were drawn from most common needs for the various world scenarios considered.

The purpose of this section is to present development plans for systems, building block elements, and technology which are essentially independent of the nature of the future world to be expected. The purpose of these development plans is twofold: firstly, to minimize the dependence of the support needs developed in the previous sections on subjective assumptions about the nature of the future; the second is to protect options for future deployment of almost any system without committing to such deployment at this time by identifying the technology which must be developed in order that those options be available at the appropriate time of need. The system and technology development plans which follow therefore attempt to be essentially independent of the exact nature of the future world, protecting the options for the major systems regardless of the exact nature of the future.

An initiative system availability development plan is presented first, followed by a development plan for the required supporting vehicles and facilities, concluding with a technology development plan, all of which attempt to meet the above stated intent.

9.1 SYSTEM DEVELOPMENT SCHEDULE

A development plan for a set of systems chosen to be representative of the assumed users' needs and to span the generic technology types is shown in Figure 9-1. The systems were chosen from the agency mission models as well as from Volume III of this study. The anticipated systems grow in operational capability as a function of time. The operational dates

PRECEDING PAGE BLANK NOT FILMED

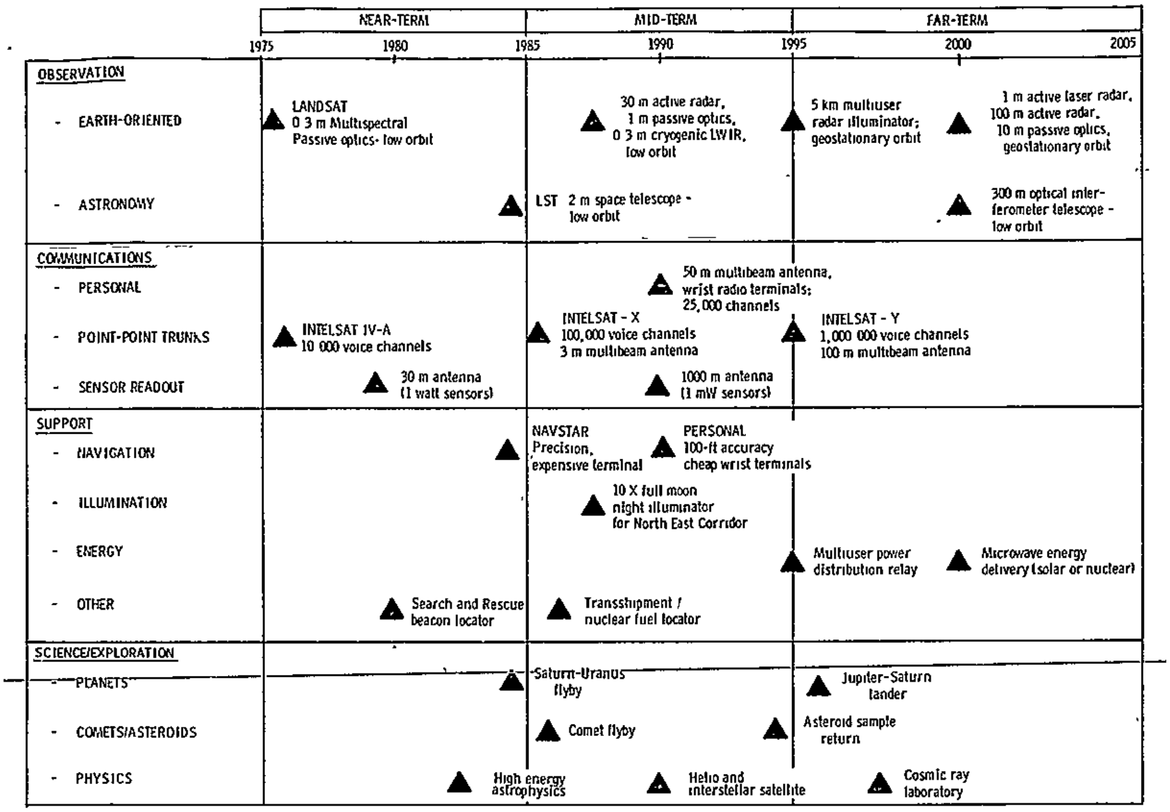


Figure 9-1. Representative Simplified Mission Model

indicated for the various systems are generally paced by the forecasted availability of technology if funded and pursued at a pace similar to past space technology programs, though in some cases a more vigorous pace may be necessary. An example of the way in which technology would enable operational system availability to grow may be found in the first line under "Earth-Oriented and Astronomical Observation." Currently, operational LANDSAT systems can be expected with 30-cm optical diameters, perhaps somewhat larger.

The LANDSAT systems would be expected to grow in optical size, number of spectral intervals, and number of simultaneous detectors, attaining about 1-2 m optics size, many thousands of detectors in a charge-coupled-array, cryogenic cooling, and combination with an active synthetic aperture radar of the SEASAT type by the 1990 time period. The far term could see growth to the inclusion of active laser radar, 10-m size passive cooled optical systems, and 100-m radar arrays. These satellites could be in higher orbits, including synchronous. Simultaneously, outward-oriented astronomical instruments would start with the Large Telescope program in 1985, featuring 2-2.5 m optics, and grow to 300 m optical interferometers in the 2000 time period, both in low orbit.

Several initiatives are combined to make up this "typical" mission model - many such models being possible. The illustrated model is not unique nor advocated.

9.2 SUPPORTING BUILDING BLOCK VEHICLES AND FACILITIES

The needs for building block vehicles and facilities can be derived from the system mission model illustrated in Figure 9-1. In the graph on Figure 9-2, these anticipated needs are shown in the four major categories utilized for presentation of the mission opportunities and commonality data. Several trends are apparent from this graph.

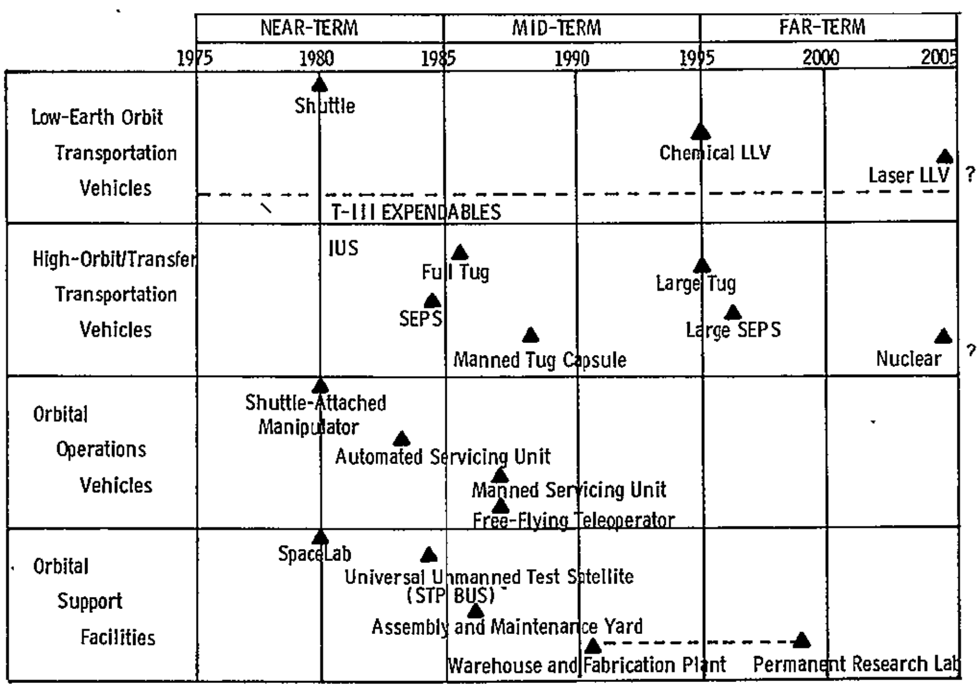


Figure 9-2. Anticipated Needs for Building Block Vehicles and Facilities

a. Low Earth Orbit Transportation. The Space Shuttle is satisfactory for the missions through the early 1990's, with the need for a larger chemical lift vehicle not occurring until about 1995; a more efficient or very much larger capability than that not being required until considerably later. Throughout this time period there is anticipated a continuing need for an expendable booster of the Titan III-C/D class for some military missions which may not permit shuttle and tug operation profiles, manned operations, or revisit.

b. High Orbit and Transfer Transportation. In addition to the Interim Upper Stage, a Full Capability Tug and the Solar Electric Propulsion Stage will be required, to be available operationally in the 1985 time period. A manned tug capsule may be required prior to 1990 should assembly and servicing of Geosynchronous Systems be needed. Larger versions of the tug and SEPS might not be required until the year 1995, and a nuclear stage not until considerably later.

c. Orbital Operations Vehicles. The shuttle-attached manipulator, which is now a part of the baseline shuttle, is required (and will be available). An Automated Servicing Unit will probably be required in the early 1980's, and a Manned Servicing Unit or a Free-Flying Teleoperator in the late 1980's.

d. Orbital Support Facilities. The Spacelab availability of 1980 should be augmented by an unmanned test satellite to replace the on-going DoD Space Test Program, and should be available in the 1984-1985 time period. An Assembly and Maintenance Yard, however defined, should be available in the late 1985-1987 time period to allow central servicing of vehicles. This is also the case for Warehouse and Fabrication Plants which are expected to be needed in the 1990 time period. The Spacelab would be expected to be augmented by or replaced with Permanently Orbiting Research Laboratories prior to the 2000 time period. These orbital facilities could grow in a modular manner to accommodate the expected increasing demands in the far term.

It should be borne in mind that a "space station," of which several versions have been defined in the past and two are currently in Phase A study, could fill one or more of the functional roles required of the "orbital support facilities" of this study. However, the term "space station" has been avoided in this report in order that the conclusions not be unnecessarily restricted by any particular definition of a "space station."

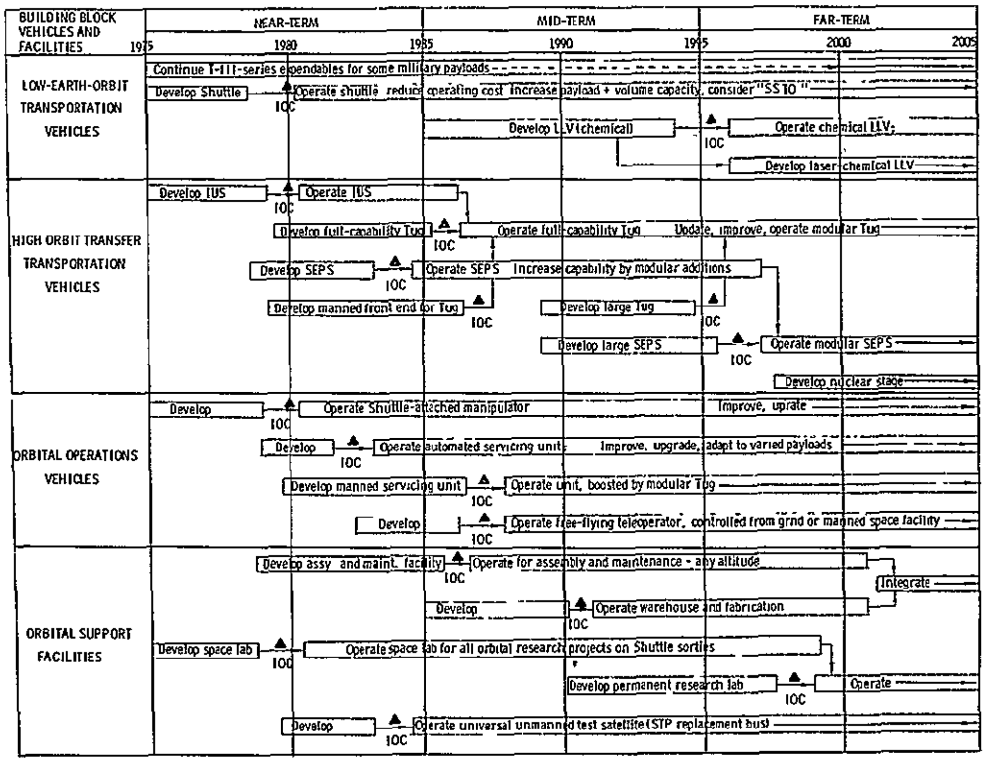


Figure 9-3. Development Plans for Building Block Vehicles and Facilities

The anticipated need dates for the building block vehicles and facilities illustrated in the previous graph are shown in Figure 9-3 expanded into a development plan consisting of a flow of activities resulting in the operational capabilities identified. As an example, in the area of high orbit transfer transportation vehicles, the Interim Upper Stage is the operational upper stage while the Full-Capability Tug is being developed. The SEPS and the Manned Tug Capsule would be developed almost in parallel. The different operational dates anticipated indicate a phasing of capability beginning in 1980 with the Interim Upper Stage, leading to the SEPS and the Full-Capability Tug in 1984-1986, and to a Manned Tug Capsule and performance augmentation for the Full-Capability Tug in 1987 or 1988. Thus, a modular tug family would be available for operations through the end of the century. The Solar Electric Propulsion Stage capability could be increased by modular additions while a new, much larger version could begin development about the 1990 time period. A modular Solar Electric Propulsion Stage would then be available for operation in the post-1997 time period. The family of high orbit or transfer vehicles thus available post-1997 would be chemical tugs, solar electric tugs, or both, with a size modularized to fit any need.

It is to be emphasized that the bulk of the orbital operations vehicles need to be ready in the 1984-1987 time period and the orbital assembly and maintenance facilities in the 1987 time period. It is expected that should any of these capabilities not be available at least in an interim form on those dates, that the systems which depend on such support could not be operational until later than indicated in the system development plan ~~(mission model). Such a slip in schedule would not be due to the lack of~~ technological ability to support those systems, but rather due to the lack of resolve to provide the required orbital support facilities.

9.3 TECHNOLOGY NEEDS

A comprehensive integrated technology development plan derived from both the system and the supporting building block anticipated need dates is shown in Figure 9-4. It shows quantitatively the requirements on technology in order to support the operational performance and need dates for the systems as anticipated in the systems development plan. The operational dates indicated by the triangles on Figure 9-4 are dates when the subsystems incorporating those technologies are expected to fly in the operational systems. Thus, a development plan for the technologies must result in flight-proven parts and techniques two to three years sooner than the triangles indicated on this figure.

The growth in capability as a function of time, moving horizontally on any one row, is apparent. As an example of the implications in this development plan, consider the first row entitled "Large Optics." A 2-m telescope is required to fly in the year 1985, thus the technology would have

TECHNOLOGY	NEAR-TERM 1975–1980	NEAR-TERM 1980–1985	MID-TERM 1985–1990	MID-TERM 1990–1995	FAR-TERM 1995–2000	FAR-TERM 2000–2005
Large Optics			2 meter UV-LWIR	1 meter LWIR-Cooled	30 meter array, UV-FAR IR	240 meter thinned array, UV-FAR IR
Large Thin Film Mirrors			30 meter	300 meter		
CW Lasers			10^6 watts, space Chemical HF		10^8 watts, space Chemical HF	10^{11} watts, ground Elec or chem DF
Pulsed Lasers		10^{-12} sec pulses 0.1 joules	10^{-9} sec pulses 10 joules		10^{-12} sec pulses 10 joules	
CCD/Focal Planes		500x500 elements Visible - IR	1000x1000 elements Visible - LWIR	5000x5000 elements Vis-LWIR multispectral	10,000 x 10,000 UV-LWIR multispect	500x500 elements FAR IR
Cryogenic Refrigerators			0.1 W @ 15° k and 10 W @ 77° k mechanical	1 W @ 4° k and 500 W @ 50° k mechanical		1 W @ 0.1° k and 1 kW @ 50° k, solid state
FAR IR Lasers/Detectors		0.1 watt CW $D^* = 10^{12}$		1 kW CW, 10^6 W x 10^{-6} sec pulsed $D^* = 10^{15}$		1 MW CW, 10^{10} W x 10^{-10} sec pulsed
Pointing and Tracking Accuracy (Space)		10^{-5} radian	10^{-6} radian			10^{-8} radian
Sat Data Relay		60 GHz - 100 Mb/s		Laser, 1 Gb/s		Laser > 100 Gb/s
Large Antennas		30 meter Linear array	300 meter Linear array	3000 meter Linear array		20 kM 2D phased array
Large Reflectors		100 M Gravity gradient 1.D.	100 m 2D diffractor @ 3 GHz		1500 m 3D diffractor @ 3 GHz	
Multibeam Antennas		2 meter dia, 50 beams		50 meter dia 400 beams		500 meter dia 4000 beams
Multiple Accesses (Voice)	10^4 Users		10^5 Users	10^7 Users		
Clock Stability			10^{13}		10^{15}	
Processing Gain		10^4		10^6		10^8
LSI Computers/Processors		Fault-tolerant Mini 1 MOPS		Micro, 10 MOPS		Self-organizing program 10^2 MOPS
Fiber Optics		3 micron fibers 10^4 fibers/bundle	1 micron fibers 10^5 fibers/bundle			
High Power Transmitters			5×10^4 watts 3 GHz		8×10^7 watts 10 GHz	8×10^9 watts 10 GHz
High Prime Power Sources			10^5 watts	10^8 watts		10^{10} watts
Advanced Propulsion				ION miniengine 10^{-3} lb_f		Laser induced Blow-off 10^{8} lb_f

Figure 9-4. Anticipated Needs for Technology

to be available around the year 1982. In this case, the technology is ready now and can readily be proven in time to meet this flight schedule. Another example under "Pointing and Tracking Accuracy" indicates 1980 as a flight date for a 10^{-5} radian pointing system, 1985 for a system with 10^{-6} capability, and 2000 for a 10^{-8} radian system. The current state of the art is indeed about 10^{-5} radians, therefore there is no problem at all in meeting a 1980 operational flight date. The 1985 flight date of 10^{-6} radians, however, implies that the technology must be ready in 1982. It is felt that such performance could readily be met given a dedicated program with that intent.

Should each and every one of the technology areas shown in this figure be developed, and should they meet the operational flight dates as indicated on the chart, they would provide all the technological needs currently seen to protect the options to deploy each of the initiative concepts identified in this study, as well as those of all the systems in the agency mission models. The cost of even such a broad and ambitious set of technology programs is still very small compared to the cost of fielding the systems themselves, or even that of only a few systems. Furthermore, because of the high commonality of application evidenced in the graphs in the preceding section for many of the technology areas shown on Figure 9-4, a general case can be made that the technology developments indicated could well fill the needs of both NASA and the DoD. Options for deployment of systems will be protected even though the systems themselves might well be different for NASA and for DoD, but nonetheless would require the same type of technology in the same time period.

10. CONCLUSIONS

This study provided several major insights, which are reviewed in this chapter.

10.1 TECHNOLOGY

Whereas in the past, technology did not permit the performance of many functions in space, the technology both available now and forecasted to be capable of being developed in the 1980-2000 time period will enable the performance of almost any function imaginable. Particularly high leverage was found in large antennas and optics, high prime and transmitted energy, lasers, microelectronic processors and sensor focal planes, and cryogenic refrigerators.

10.2 INITIATIVE SYSTEM CONCEPTS

The high leverage technology will allow the fielding of a large number and variety of system concepts, with over 100 such initiatives having been identified in this study. While none are advocated per se, the set identified, as well as many other sets possible, utilize a number of unifying principles applicable to guide the development and operation of space systems for the rest of this century.

These principles include extending the benefits of space services to very many, very tiny, cheap, simple, and personal user sets by deliberately making the satellites large and complex, even if they become heavy and expensive as a result. (The cost of the user equipment, as well as the sum of the user and satellite equipment are minimized, while performing functions not otherwise possible); use of passive reflectors for routing energy generated on the ground or in space; use of space for the gathering, processing, and dissemination of information; combination of functions into multifunctional satellites; and others.

The application of these principles will allow space to become useful and relevant in the everyday lives of large numbers of average citizens, provide a great range of services to industry and all levels of government, provide an economic incentive for investment by capital in the return implicit in the user charges for those services, and support sophisticated programs of science, exploration, and the advancement of knowledge. Space could also materially affect the balance of power in Defense applications, the details of which are treated in the classified version of this report.

The initiatives identified fall into different risk and time-frame classes varying from low-risk applications of today's technology in the early 1980 period to identification of concepts requiring great advances in technology not likely until the end of the century, and possibly posing some hazards associated with their operation.

Technology programs were also identified which will protect the options to develop most of the identified or likely initiatives, without requiring great expense or commitment to any such initiative.

10.3 ORBITAL TRANSPORTATION AND SUPPORT

The large and complex spacecraft identified will require assembly, initialization, servicing, and modification in orbit in order to be feasible, economically attractive, or both. Accordingly, orbital transportation vehicles and orbital supporting facilities have been identified which could meet the needs anticipated for both NASA and DoD in the time period, and which are likely to be needed regardless of the exact nature of the future world. Six alternate world futures were examined in this study toward that end, and these conclusions generalized to other world futures as well.

Many mission opportunities were found to exist for the Space Shuttle, which was found to be an exceedingly useful low-orbit launch vehicle, as well as some opportunities for much larger reusable lift vehicles and some expendable ones. Many mission opportunities were likewise found to exist for orbital transfer vehicles including the Interim Upper Stage, Full Capability Tug; a much larger tug with a manned capsule, and a Solar Electric Propulsion Stage. Many opportunities were also found for the application of manned and/or unmanned vehicles or facilities for fabrication, assembly, initialization, servicing, and modification of spacecraft.

Development plans for such facilities were identified which would probably be able to support most initiative concepts identified in this study, or likely to be identified in the near future, regardless of their exact characteristics. The degree of common need for such transportation and support vehicles and facilities by the postulated military and civilian programs in the 1980-2000 time period was found to be high for most of the more moderate views of the future. It seems likely that one set of vehicles and facilities could support both NASA and the DoD.

10.4 ROLES OF MAN IN SPACE

This study did not attempt to address differences (or similarities and advantages (or disadvantages) of manned versus unmanned space operations. While no initiative was identified which would be impossible to orbit and operate without man in space, many of the larger initiatives could well become economically attractive only by large scale use of man in space. In this light, whereas past justification for man's participation in the space program tended to emphasize exploration, research, and science, a very practical application-oriented case could be made for man's participation in space in the next 25 years. Since many of the initiatives and system concepts identified will require assembly on orbit, servicing, initialization, and reconfiguration of large, very complicated structures, assemblies, or groups of assemblies, man's primary role could be viewed as that of performing such functions (though tradeoffs between manned versus automated approaches clearly must be performed).

Whether such functions are performed by hand in EVA or using tele-operator devices operated from space, man will of course need life-support facilities, "yards" and "warehouses" for assembly and servicing, research and test stations, etc. Thus, a progression of increasingly capable "space stations" might be needed, which are viewed as supporting facilities for a working force to assemble and keep operating the groups of satellites which perform earth-oriented services (which are in themselves accepted in terms of their contributions to life on earth). Viewed in this light, a manned space program may take on a vitality not possible otherwise.

10.5 BUDGETS

~~The programmatic information developed in this study indicates~~ that the budgets required to develop, orbit, and operate the civilian initiatives identified (including those conceived during the course of the study, gathered from other studies and sources, and those in the 1973 NASA Mission Model, which is about 160 programs all told) is estimated to be less than five billion 1975 dollars per year averaged through the year 2000. Similarly, less than 10 billion 1975 dollars per year averaged through the year 2000 would be required for both civilian and military programs for most non-catastrophic futures. This assumes, of course, that the funding peaks can be either properly phased or amortized into the total time period, and may call for some imaginative arrangement with the financial community to absorb the peak demands and be paid back during the more slack times. Enormous increases in services provided by space can thus result from slightly more than doubling the budget of the space program.

10.6 PUBLIC EDUCATION

The general public is not aware of the possibilities which space has for influencing their daily lives (nor is a fair fraction of the space community for that matter). It is vital that the perspectives of space operation, and the types of services the resulting space system initiatives could provide, be exposed within the technical community and to the public at large. The long-range goals for the space program should be selected, and budgets requested for its support, so that a program of balanced national priorities can evolve. The education of the public and its representatives in government is seen as a vital step toward ensuring that the space program is allocated appropriate attention and an appropriate share of the national budget.