COMMUNICATION SATELLITES

Guidelines For a Strategic Plan

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A REPORT OF THE COMMUNICATIONS SUBCOMMITTEE OF THE SPACE APPLICATIONS ADVISORY COMMITTEE (SAAC)

NASA ADVISORY COUNCIL

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1

INTRODUCTION

"Future developments in space-based communications and information systems will continue to revolutionize our daily lives at home and at work."

U.S. National Commission on Space (1986)

History has shown that leadership in communications carries with it substantial economic benefits and political advantages. To maintain and augment the leadership that the United States has enjoyed and to ensure that the nation is investing "sufficiently and wisely"[1] to this purpose, Congress has asked NASA to prepare a strategic plan for satellite communications research and development. This committee proposes, as a national objective, maintaining U.S. preeminence in providing commercial satellite communications capabilities to the world. The committee has generated guidelines and recommendations for a NASA plan to support this objective and for the conduct of NASA's communication satellite research and development program over the next 25 years.

Communications are essential to all aspects of business and national affairs as well as our modern cultural well-being. The world market for telecommunications and computer products and services approached $500 billion in 1985 and is expected to grow to more than $880 billion within 5 years.[2] Currently, more than half of all U.S. workers—from corporate executives to secretaries—spend their time handling information.[3] General Motors Corp. has estimated that one-half of all money spent on factory automation is for communications. Communications can reduce distance and uncertainty, whether for the farmer who needs weather and market information or for a global automobile manufacturer weaving all its management, accounting, inventory, design, and manufacturing operations into a unified global system. It is clear that communications, which used to be merely a cost of doing business, has increasingly become a competitive advantage.

Information is a primary resource that increasingly affects productivity and has become a principal element in the economies of the United States and much of the industrial world. The rapid growth of microelectronics and the merger of computers and communications has made this transformation possible. Worldwide, reliable, and interconnected networks that permit rapid access to information, people, and ideas have made "information economies" possible. The acquisition and dissemination of information will become an increasingly larger component of industrial and commercial activity. Dr. Louis Branscomb, formerly Chief Scientist, IBM, has observed that, in contrast to today, where great amounts of information are collected and stored in libraries or data bases for occasional access and analysis,

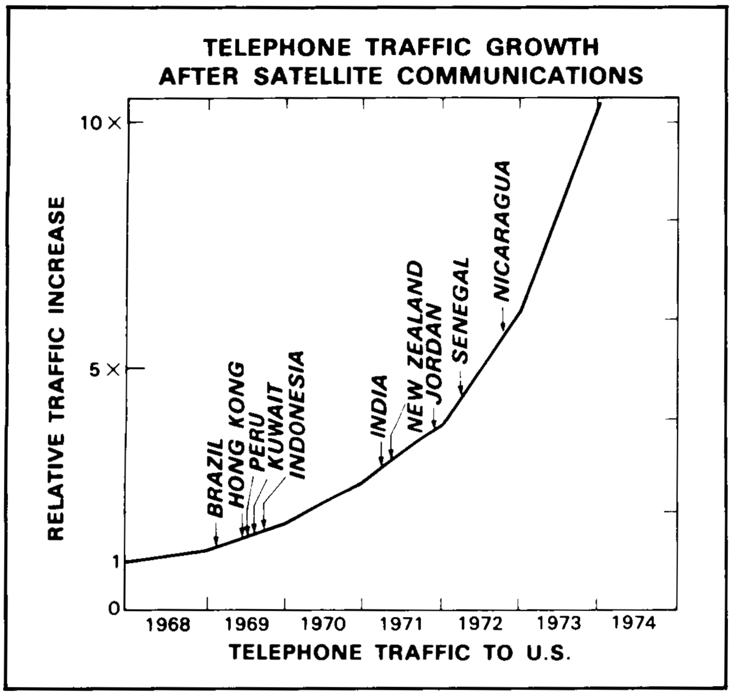
> In the next 100 years, much information that is stored today may not have to be stored at all. It may be cheaper to reconstitute or reacquire information from basic elements each time the information is needed. . . . It may be easier—and better—to reobserve something than to retrieve a stored recollection of it.[4]

The fullest development of such information distribution services will require global communications networking on a scale not yet imagined. Satellites will be a necessary component of these networks.

Role for Communication Satellites

In today's direct-dial world, it is difficult to remember that the first high-quality transatlantic telephone calls began a mere 30 years ago with an undersea cable, TAT-1, of 36 circuits. By 1965 this number had grown to 328 circuits on four cables. With the advent of the first communications satellite (Intelsat-I), 300 circuits were added. Today, there are 30,000 circuits across the North Atlantic. Using a mix of cable and global satellite communications, one can call virtually any telephone from any other telephone in the world. With the advent of communication satellites, the telephone traffic to and from the continent of Africa increased 100 times. Twenty-five years ago there was no capability to share in real time, via television, events from around the world, and there was no reliable communication with our ships at sea. With communication satellites, hundreds of millions of people worldwide watched the 1986 World Cup match in Mexico City, and over 4,000 commercial ships are now equipped for worldwide direct-dial telephone communication.

Today's communications systems comprise mixtures of conventional terrestrial networks and satellites, which have provided new kinds of services. Similarly, the explosive growth of terrestrial fiber optics has created new services that augment the capabilities of existing systems and significantly enhance all communications ser-



The volume of telephone traffic between the United States and third world nations soared more than ten times as newly installed ground stations made satellite links available. In specific instances, the increase was even more dramatic: between Senegal and the United States, traffic increased 100 times; between Kuwait and the United States, 20 times; and between Jordan and the United States, 50 times.

vices. This has led some to conclude that fiber systems will completely supplant satellite systems. Fiber optic transmission does offer dramatic new technical capabilities and cost reductions in applications where its higher quality at extremely high bandwidths can be used. It is expected to be the most economic solution to the needs of high-density traffic routes between major population centers. Because it does not have the transmission time delay associated with the longer satellite path, it is preferred for interactive voice communications. Fiber provides inherently greater privacy than does satellite transmission, and the channel bandwidths possible in fiber cannot be matched by today's communications satellites. However, it is inappropriate to regard fiber optics systems and satellite systems as mutually exclusive; viewing them as complementary is most likely to produce the best mix of telecommunications facilities needed by a modern nation.

Satellite communications systems do have certain fundamental, invariant advantages over terrestrial systems, regardless of whether they are coaxial cable, microwave relay, or optical fiber. Satellites are uniquely suited to:

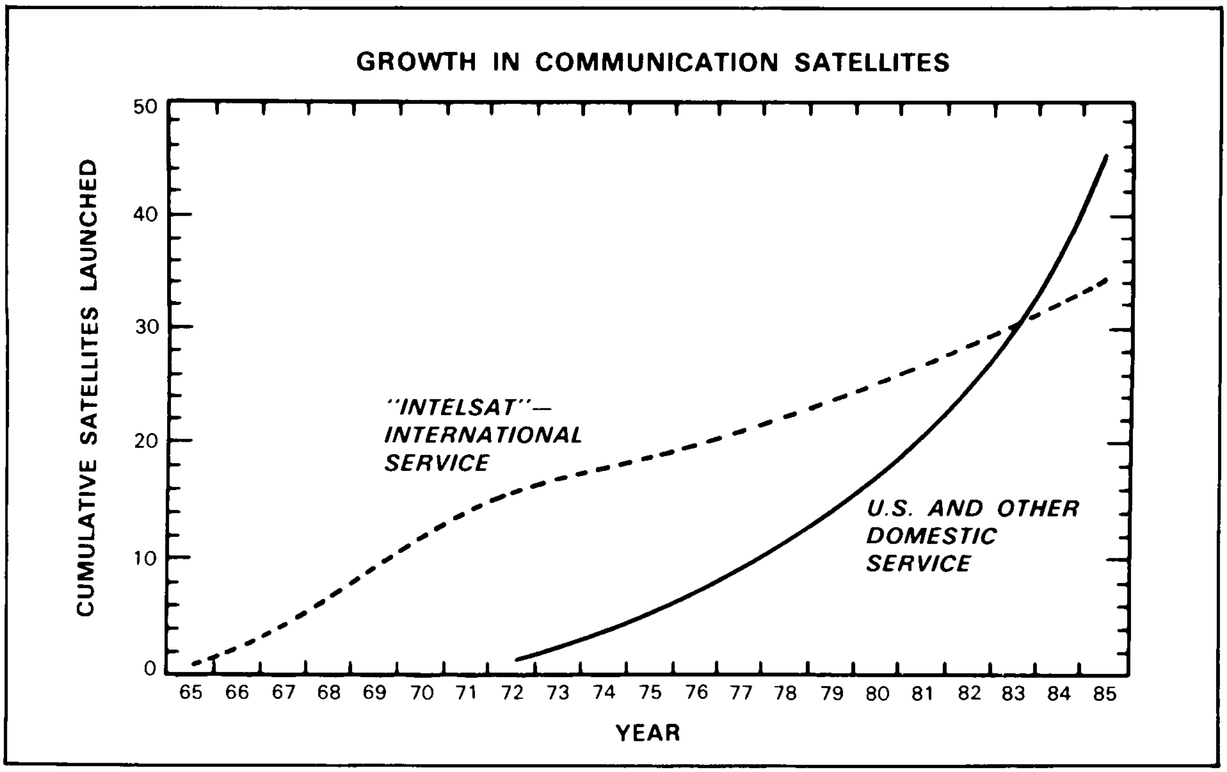
1. *Broadcast-type applications* (point-to-multipoint communication). A satellite can cover a very large area, for example, the entire United States, permitting simultaneous reception by all stations throughout that area, without regard to natural obstacles that might present difficulties to terrestrial systems.
2. *Quick reaction services* such as rapid service for new markets, the establishment of new networks, or emergency restoration of damaged facilities.
3. *"Thin-route" connectivity* of extended networks to air, land, and sea platforms, as well as long-distance transmission over difficult terrain. A satellite can provide direct service between any two end users without the normal terrestrial telephone network hierarchy.
4. *Mobile service* outside of metropolitan areas. A satellite can provide transmis-

sion to and from a moving station, for example, an auto, airplane, or ship at sea. Such circuits can be of toll quality and may be direct dialed. In the foreseeable future, satellites will provide tracking and data relay services by space-to-space data transmission.

These strengths of satellite communications can and should be exploited in planning for advances in communications technology to meet the future needs of an information-intensive society.

Communication satellites stand out as the first and most important commercial application of space technology. There has been spectacular growth in satellite communication, largely as a result of American leadership. Some 100 commercial satellites have been flown throughout the world and 58 more are being built. This activity represents some $3.5 billion in revenues each year. By the end of the century, the global marketplace is expected to exceed $40 billion.

Communication satellites saw their first widespread application in providing international telephone and data transmission service, a market which they rapidly dominated. Starting in 1972, satellite services were allowed to compete in the domestic U.S. communications market. The growth in this part of the telecommunications market, in the United States and in other countries, was even more rapid than the growth in international service. Essentially, all the satellites that provided service, domestic and international, were U.S. built.



. . . satellite communications will play a pivotal role in realizing the dream of communications: to be able to exchange and use information on an individual face-to-face level without restrictions of any time or place.

Koji Kobayashi, Chairman, NEC
Computers and Communications
MIT Press, 1986

We need not await the fulfillment of Dr. Kobayashi's predictions to convince ourselves of an information and communications explosion. Today's world is mobile and our institutions are becoming global. We need only look at how rapidly the manufacture of an automobile is becoming an international effort. Designing the "world car" employs engineers and designers in many countries. Materials, parts, designs, and financing are acquired from many different parts of the world and must all be managed to ensure timely arrival in the right place. The nervous system of emerging global institutions will be high-rate communications with worldwide connectivity.

The Developing World

Communication satellites play an important role in the developing world. They provide instant coverage of a wide area. Developing nations, especially those with few urban centers and poorly developed transportation systems, cannot afford the time or the cost of establishing adequate communications through the use of terrestrial systems alone. In addition, the communication needs of the developing world create a large, untapped, potential market for the sale of communications products and services. The commercial and political benefits flowing to nations serving this emerging market will be significant.

Nevertheless, the developing nations do have concerns about their future access to communication satellite services, as the Commission on Space notes:

> There have been and continue to be pressures from less developed countries for guaranteed equitable access to the use of space and its resources. This has been particularly visible in meetings of the International Telecommunications Union devoted to allocating geostationary orbital positions and radio frequencies for communication satellites. Many less developed countries have pressed for long-term rigid planning to assure their access, while the United States has argued for a more flexible approach.[5]

The United States can realize flexible rules for access to geostationary orbital positions and radio frequencies if it pursues a vigorous technology development program that will demonstrate to the developing nations that we have means to ensure that this valuable resource will not be saturated.

The Challenge

During the past three decades, the United States has been the leader in the communications industries, in some large measure as a result of the development of satellite communications systems. Although American dominance in some industrial sectors is ending under the weight of great economic forces—such as the increasing availability of skilled, low-cost labor in developing nations—it is still possible to preserve our dominance in high-technology satellite communications if our leadership position is nurtured.

We should not repeat the mistake made in 1973 when NASA's communications program was "phased down." The success of the satellite communications industry was the result of NASA's robust program during the 1960s. Paradoxically, this success was used to argue that an industry had been established that could support its own research and development. Following 5 years of NASA "phase down," Congress responded to industry's urging that NASA reinstitute a vigorous satellite communications technology program. Congress' clear mandate to NASA was to ensure that the United States maintain its position as a leader in satellite communications technologies.[6] This stewardship was reinforced in NASA's 1983 authorization when Congress asked it to develop a long-term plan to continue growth in the use of communication satellites, and to increase the efficient use of the radio spectrum and the geostationary arc.

The leadership position of the United States—politically, technologically, and economically—depends on forward-looking and innovative approaches. This is especially true in the increasingly competitive world of high technology. It is in the national interest that the U.S. government foster the advanced technology communication systems that will serve the United States and other nations. It is the opinion of this committee that, in satellite communications, this will not occur without direct government involvement.

Indeed, the Japanese and Europeans clearly recognize the importance of government involvement and government-industry cooperation. Japan and Europe have targeted communications technology—including satellite technology specifically—for major coordinated efforts because of the pivotal role communications and communication satellites play in national development and leadership.

What NASA Can Do

NASA has a clear role in contributing technology to new satellite systems. In its Space Applications program, NASA should develop the new, high-risk satellite communications technologies necessary to lay the groundwork for full national and worldwide connectivity and to allow more efficient use of the radio spectrum and the geostationary arc. The long-term plan for NASA must anticipate communications needs and applications through the first decade of the twenty-first century and, to fulfill its congressional mandate, NASA must commit itself to continuing programs during this period. A comprehensive and aggressive research and development program is a necessity if NASA is to play its proper role in maintaining U.S. preeminence in satellite communications. The substance of this program is delineated in Section 4 (Guidelines for a National Satellite Communications Plan).

Observations and Recommendations

The consensus of the NASA Space Applications Committee, which is supported by interviews with representatives of the communication satellite industry, is that satellite systems will be an important component of communications in the future, that competition from government-subsidized foreign companies is serious, and that the time is at hand for the U.S. government to support American industry in retaining a dominant role in world communications. It offers the following observations and recommendations for action.

Observations

1. World leadership in communications carries with it substantial economic benefits and political advantages.
2. Communication satellites have unique capabilities that allow them to play a critical role in national and international telecommunications.
3. Communication satellite systems are still in the early stages of technical development. As they continue to advance technically, they have potential for stimulating new domestic and international markets.
4. U.S. leadership in communication satellites is being challenged by Japan and Europe through coordinated government and industry efforts.
5. Retention of a dominant U.S. position in satellite communications will require steady government support.
6. NASA's current satellite communications program is consistent with the initial steps in our proposed guidelines for continued progress in telecommunications.

Recommendations

The committee proposes the following recommendations for national support of U.S. industrial competitiveness in providing future satellite communication systems. They are listed below and are amplified in the following sections.

1. The NASA space program goals and objectives should reflect the importance of satellite communications.
2. NASA should support a sustained national program in the development and application of communication satellite technology.
3. NASA must work actively to overcome industry perception of the uncertainty of NASA's long-term commitment to space communications.
4. NASA should continue its support of the current space applications program as a fruitful approach to long-term research.
5. NASA should devote a segment of its space communications program to far-term speculative research, recognizing that only some projects will provide payoffs in applications.

The vehicle for implementing these recommendations should be a strategic plan for satellite communications, prepared by NASA. Guidelines for the scope and content of such a plan are provided in Section 4.

2

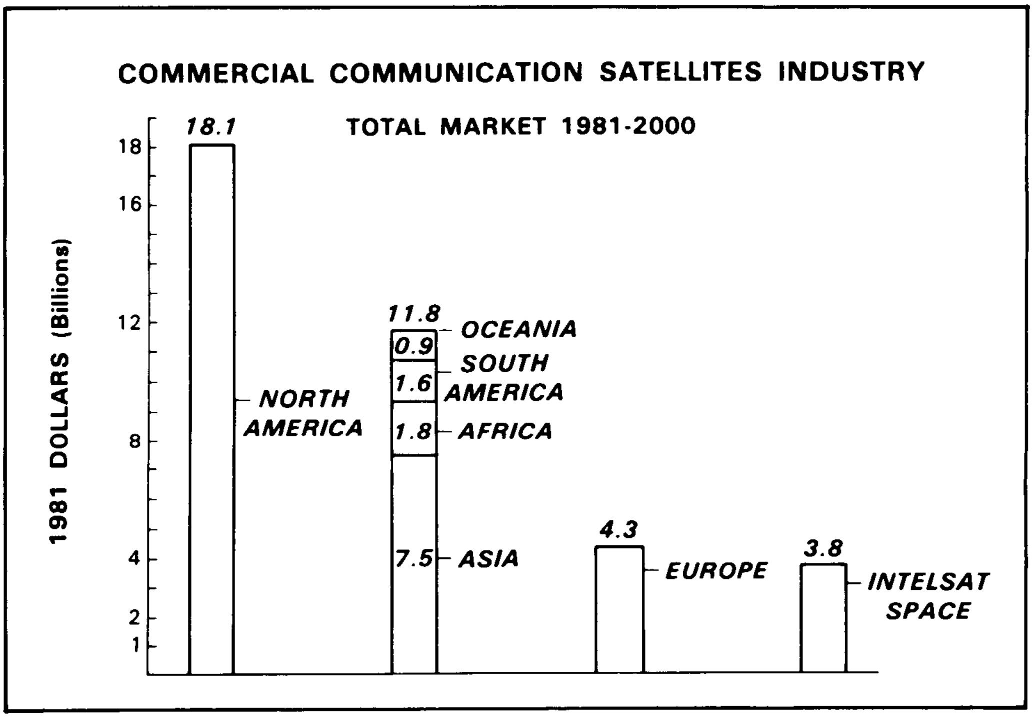
FUTURE ROLE OF SATELLITES

It is ironic that communication satellites found their first economically significant application in wideband trunking communications, a service that does not particularly exploit their natural advantages. As has been discussed, this service is expected to become the province of fiber-optic cables; in the future, communication satellites will play four principal roles.

Broadcast Applications

The unique broadcast capability of satellites stems from the ability to provide wide geographic coverage from a single point in space. A number of valuable communication services can best be provided by exploiting that capability. Among them are:

- Video teleconferencing among multiple points, which has not lived up to earlier growth expectations, now appears to be due for rapid expansion as a result of more efficient video compression techniques, which have made it more economic. There is also a growing awareness of its value in reducing travel costs, as a tool to improve productivity and the quality of decision making, and in dissemination of educational program material.
- Large, multipoint networks will become commonplace for point-of-sale transactions, inventory control, banking, remote printing of news, and similar applications. Very small aperture terminals (VSATs) will be counted in the hundreds of thousands in countries like the United States.



This early market study of the communication satellite industry was performed for NASA-LERC in 1981. Its 20-year total market projection of $38 billion is conservative, corresponding to an average annual market of $1.9 billion. Recent estimates by Satellite Systems Engineering for the period 1986–1990 indicated an annual market of $3.3 billion.

- Home information services in all categories, from entertainment, electronic mail, business and personal transactions, to telecommuting, will become available with wide-area coverage through exploiting the broadcast advantage of satellites.
- Although the foreseeable needs of the developing countries for telecommunications to assist in nation building are much simpler than those of the developed nations, broadcast services—both audio and video—are vitally important for cultural purposes, entertainment, health service delivery, and agricultural training by television broadcast.
- Document transfer by high-speed digital facsimile, already significant in Japan, will grow rapidly, largely at the expense of older technologies (e.g., telex). Electronic mail is now growing at the rate of 30-40 percent a year, taking market share from telex, telephone, and postal services. Satellites are the best means of providing such services over wide geographic areas and to less densely populated regions.

- Further into the future are services now regarded as visionary. One such example is worldwide direct source inquiry for data collection which may some day replace inquiries to structured data bases. The need to gather and analyze information instantaneously on our global environment requires the collection and transport of data exceeding by orders of magnitude currently available capabilities.

Quick Reaction Services

The ability to deploy satellite earth stations rapidly or to reconfigure an existing network quickly is an important capability for information systems. The inherent flexibility of satellites gives them this quick-reaction capability.

- Telecommunications services of all kinds can be more quickly extended by satellite than by terrestrial means into areas that are developing with unforeseen rapidity. Difficult geography can be surmounted, and the resultant system more easily maintained, if satellite systems rather than terrestrial means are used.
- Quick restoral of facilities which have been destroyed or damaged by disasters is an emergency response capability of great importance to a society that is increasingly dependent upon continuous communication.
- Networks can be quickly established and reconfigured as needed to handle varying traffic loads and to provide coverage of major sporting events or major events that require rapid dissemination of news for public information purposes. A given transponder can interconnect Miami and Boston, be switched to serve Los Angeles and Seattle, or connect all four cities simultaneously, thus creating an instant network. The national importance of this flexibility should not be underestimated as a means of informing the public at the time of natural or man-made disasters.
- The inherent flexibility of the communication satellite, together with its thin-route efficiency and multipoint capability, makes it a vitally important medium for use in the sophisticated flexible networking systems of the future. These networks will provide emerging services like Integrated Services Digital Network (ISDN), Software Defined Networks (SDN), and enhanced 800 services, which depend upon computation and data bases embedded in the communications system itself.

Thin-Route Connectivity

Satellites provide the most cost-effective means for connecting a limited number of widely separated locations where the traffic density among those points is relatively low. This capability will be as important in the highly developed world as it will be in the developing world, for example, in serving rural areas and in providing direct access to the customer's premises in networks tailored to that customer's specific needs.

- The first of a new generation of manufacturing facilities should begin to appear in the near term. Many of these will be constructed outside the major metropolitan areas to provide better quality of life for the much smaller work force and will cost less to build and operate. All will be much more dependent on information flow as the result of their greater degree of automated assembly, computer-aided design and manufacturing, and closer interdependence with suppliers. For plants constructed in what are now rural areas, a link to a central headquarters to provide inventory control and CAD/CAM and MAP-type functions is particularly well served by satellite communications.
- Satellite communications clearly are the most desirable means for satisfying the internal telecommunications needs of developing countries. External telecommunications of low traffic density also will be dominated by satellite-based service. However, the earth station facilities must be small, cheap, and easy to operate and maintain if they are to be truly useful in the developing world.

Mobile Service

The wide-area coverage offered by communication satellites makes them ideally suited to mobile users.

- In developed countries, mobile communications for rural and intercity applications as well as position location services will become a reality in the near term. Satellites will be the preferred medium. The growth of this market largely depends on the availability of small, low-cost terminals for the many types of mobile platforms to be served.
- In less developed countries, communications that provide mobile and position location services will become important for "back country" applications.
- Space-based facilities, such as the space station or orbital manufacturing facilities that will emerge as the commercialization of space develops, will require communications connectivity.
- Further in the future, but clearly foreseeable, is the ultimate in mobile communication—personal communication. Initially, such a service would probably be limited to providing access to information data bases and two-way communication over long distances. Ultimately, world-wide connectivity between individuals will become a reality.

3

COMPETITION FROM ABROAD

Background

Through its pioneering technology developments and space experiments over the past 25 years, NASA fostered the now flourishing space communications industry. Following the success of a series of experimental space communications projects in the early 1960s—Echo, Relay, and Telstar—NASA's Syncom II satellite, launched in 1963, first demonstrated the feasibility of communication via satellite in geostationary orbit. These successes led to the launch in 1965 of a commercial Syncom follow-on, the Intelsat I, by the International Telecommunications Satellite Consortium (Intelsat). Five generations of Intelsats have followed and a sixth will be ready for launch in 1987. Fifteen Intelsat satellites were in space by 1986, providing services to more than 140 countries.

The success of Intelsat gave impetus to the domestic satellite markets, Canada's Anik A1 (built in the United States) in 1972, and the U.S. Westar-1, in 1974. These were followed by more than 30 domestic satellite assignments in the North American segment of the geostationary arc by 1986. Commercial satellites have created a global market for communication satellite hardware and services that is expected to exceed $40 billion per year by the end of the century.

All these satellite systems exploited technology developed by NASA during the period 1960 to 1973, at which time the policy decision was made to terminate NASA's role in the development of communication satellite technology. This occurred as a result of budget pressures and was due, in no small part, to the tremendous success of the program. An industry had been established and it was expected to support its own research and development. During the past dozen years, industrial R&D in space applications has produced evolutionary advances but they have not been sufficient in the face of rapid gains by foreign competition. The advance of space industries in Europe and Japan has been made possible by direct and indirect subsidies from governments whose policies recognize the long-term importance of satellite communications. The seriousness and intensity of this foreign competition is exemplified by the Franco-German and Japanese direct broadcast satellites, which employ technology at the limits of the current state-of-the-art.

The real strength of the Japanese and European approaches derives from their clear focus, which is established at the national level. The Japanese system operates with a broad technological base and allows the coordination of diverse industrial resources to pursue particular market areas. Similarly, the Europeans have a multinational, integrated approach to achieving their goals in capturing future communication satellite markets. Both the Japanese and Europeans are developing ground systems and launch vehicles, and will support them with favorable financial arrangements. The political realities in the United States argue against the likely coordination of private sector resources in such a comprehensive manner. The U.S. can respond only through the continuing development of superior technology. The role of the U.S. government must be to foster this technological response. Among the civil agencies in the United States, NASA is the only one that has the facilities, the managerial and technical expertise, and the resources to sponsor a program equivalent to that of Japan or Europe.

Japanese Activity in Space Communications

The Japanese activity in space communications can be seen as part of their national strategy to develop the information-intensive society of the twenty-first century. It is consistent with Japanese determination to be dominant in all phases of telecommunications and computers. Japan is already a major world force in fiber optics, terrestrial radio, telephones, and switching systems. Japan has built more than 75 percent of the world's Intelsat type earth stations. In space, Japan—through the National Space Development Agency (NASDA)—is continuing the design and manufacture of ever more complex spacecraft as well as the development of Ariane class expendable launch vehicles.

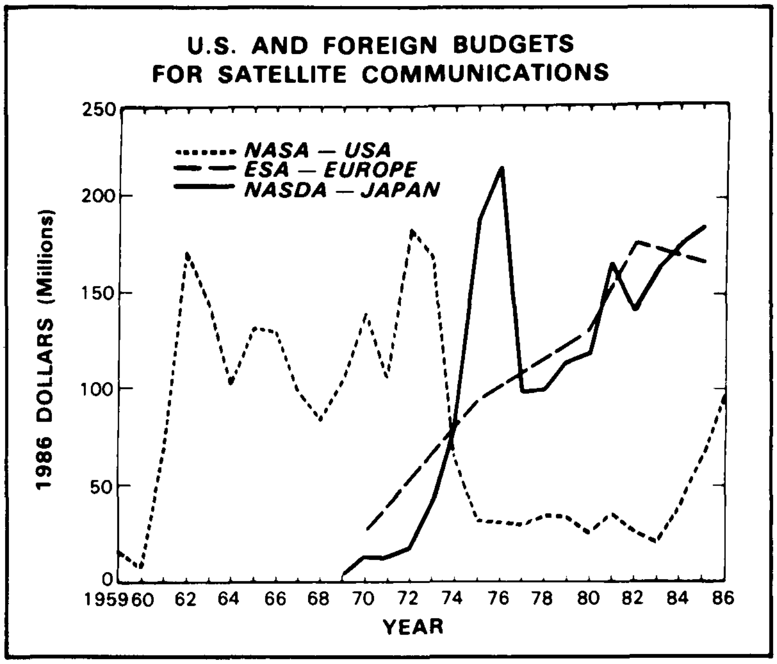
NASDA has developed communication satellite expertise by "learning" through partnerships with American aerospace firms. These partnerships have produced a family of meteorological satellites and two communication satellites, CS-2A and CS-2B, which have been operational since 1983. This competence is furthered by a series of six engineering test satellites (ETS), Japanese built, which will test satellite subsystems in space. ETS-V, which is scheduled for launch in 1987, will be used for land, maritime, and aeronautical satellite communications experiments. By 1990, the

Japanese arc will be augmented by two Japanese-built communication satellites, CS-3A and CS-3B, and two broadcast satellites, BS-3A and BS-3B, built by NEC and RCA. By 1992, Japan expects to launch ETS-V1 and INS satellites (equivalent to Intelsat VI) on their H-2 rocket, which will place 4500 lbs. into geostationary orbit.

The principal Japanese spacecraft manufacturers, NEC and Mitsubishi Electric, supported by the laboratories of KDD, Fujitsu, Toshiba, and others, are producing major advances in communications and broadcast satellite technology that are comparable to anything in the United States. Solid-state power amplifiers used in RCA's Satcoms include Japanese field effect transistors (FETs). Their CS-3 communication satellite will use gallium arsenide solar cells—a major step forward in power generation. There are major Japanese advances in the development of the transponder electronics of CS-3 and in the payloads of the experimental satellites ETS-V and ETS-V1, which are reducing size and weight by using innovative solid state microwave and millimeter-wave integrated circuits.

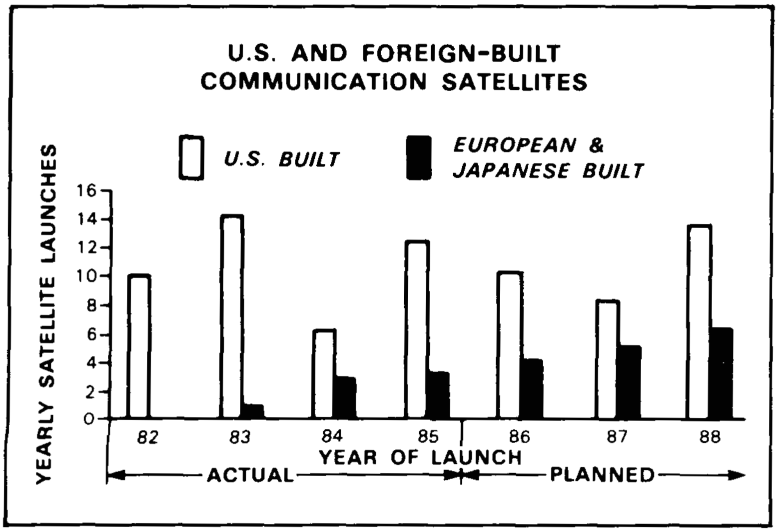
European Activity in Space Communications

In 1978 Dr. Walter Lutsch, European Space Agency Telecommunications Director, stated as a basic policy that ESA communication satellite programs would sponsor technology developments to support European companies that could compete in the international satellite marketplace, and would develop satellites that could serve European needs in telephone sevice, data communications, and broadcasting.



NASA's budgetary support for communication satellites research and development dropped sharply in 1972. The steady investment of the previous years provided the foundation for U.S. dominance in this field. Since 1972, government investment by the Europeans and the Japanese has far outstripped that of the United States, to the point where the U.S. position is now seriously threatened.

By 1986, these objectives had been more than met in the ESA satellites OTS-2 and the ECS series which are now operational in the Eutelsat system. European business decisions led to the organization of consortia such as Satcom International and Eurosatellite. The members of these organizations had been partners with U.S. firms on Intelsat satellites and had learned much. Subsequently, these consortia successfully competed against the United States on Arabsat and Inmarsat, and are building high-power direct-broadcast service satellites



U.S. manufacturers have designed and built the most complex satellites and are still leaders in this field, but Europe and Japan are hard at work and are winning an increased share of the market. The launch difficulties of the 51-L shuttle and the Ariane launch vehicle have resulted in postponement of several communication satellites, but this will not change the relative position of U.S. and foreign satellite builders in the short term.

for French, German, Swedish, and pan-European TV distribution. National satellite interests developed under ESA guidance have led to these current domestic satellites: Telecom-1, France; Italsat, Italy; and Kopernikus, West Germany.

Ten years ago, the Europeans made an accurate and farsighted decision to develop the launch vehicle Ariane. It was to use demonstrated technology, to be virtually dedicated to geostationary satellite launches, and to attempt to capture 35 percent of the world's commercial launches. They achieved what they set out to do.

In 1986, the impressive result of ESA-sponsored research in launch vehicles took on great import with the Challenger disaster. Dr. R. Collette (ESA Communication Satellite Head) at the Space-Tech conference (May 1986) in Geneva, stated that Europe is preparing for a new phase of space competition with the United States which will involve, not only new space platforms and conditional involvement in the U.S. space station, but also new satellites to provide orbital data relay, switching in space, and laser intersatellite links.

The European satellite activities, both at the ESA and national levels, are directed toward developing technologies that make their manufacturing consortia competitive in the global marketplace, and provide unique capabilities where United States and European competition is involved. For example, they have developed antenna competence (Italy), three-axis satellite stabilization competence (Germany), and 12 GHz travelling wave tube amplifier competence (France and Germany). The Europeans are now developing technologies (laser cross-links and on-board processors) to accommodate the markets they perceive will exist. These technologies are at the same level as NASA's Advanced Communications Technology Satellite program. Other technologies are directed toward interconnecting postal telephone and telegraph (PTT) switching centers at the standard European hierarchical data rates, toward exploiting higher frequencies in the 40-50 GHz range, and enabling high-speed data paths (gigabits) to interconnect national data centers directly. This high-speed interconnect development using communication satellites will be a critical technology application as the world moves toward a global information "village."

4

GUIDELINES FOR A NATIONAL SATELLITE COMMUNICATIONS PLAN

In this section we propose guidelines by which NASA can prepare a strategic plan for developing satellite communications technology and from which, in turn, detailed program plans can be developed by the responsible NASA centers. The detailed plans should be structured in conjunction with industry to identify those high-risk and critical technologies needed to keep U.S. industry competitive in the global marketplace.

There are three stages of development that characterize the communication satellite industry from its inception until well into the twenty-first century. They are discussed below to establish a context for the proposed guidelines.

The First Stage

The first stage, now coming to a close, is based on a communication satellite operating mode no different in principle than that of Syncom I. All current commercial communication satellites operate in a simple frequency-translating mode, much like ground-based microwave repeaters. In this mode, a signal is received at the satellite, shifted in frequency for retransmission (to avoid interfering with the receiver), amplified, and rebroadcast to earth.

The signals transmitted up to the satellite may be a single, wideband television channel or may be a collection of voice or data circuits aggregated into a wideband trunk circuit. In the latter case, the uplink signals, when retransmitted to the ground, are still grouped as they were received in the satellite; only on the ground can the signals be separated and sent to different destinations via ground switches.

The earliest communication satellites rebroadcast their signals indiscriminately over the entire earth's surface visible from the satellite. With recent more sophisticated communication satellites, the rebroadcast signal may be assigned to a directive antenna beam that covers a particular small area of the earth or can be moved to cover different areas. This is an important development because it makes much better use of scarce satellite transmitter energy.

Notwithstanding these substantial refinements and the significant enhancement of traffic capacity relative to the earliest communication satellite systems, the fact remains that all current systems use the same basic principle of satellite retransmission between fixed-earth stations without any on-board signal processing. In this sense, they are still on the same technical plateau as Syncom I in their principles of operation.

In recent years, as the stage one technology has matured, research and development activities in materials, components, and subsystems have stimulated new approaches for satellites as well as new communications applications for satellite systems. Technology developed in this phase has revealed the potential for an entirely new generation of communication satellites, which is discussed in the next section.

The Second Stage

The second stage in the communication satellite industry will be marked by a major change in the character of the services provided and in the communities employing these services. Where current satellite circuits are predefined and established between fixed points, the next generation will see the development of services built around the capability for flexible information distribution among dispersed, changing locations.This flexibility will be manifest in the dynamic switching of circuits on board the spacecraft, in the mixture of terminals that will be serviced with varying bandwidths at varying geographic positions, in the provision of service to mobile users, and in the direct connection of service between hemispheres by intersatellite crosslinks.

There is world-wide competition in the development of switching technology for terrestrial systems, driven by economic pressures to provide low-cost, point-to-point telephony to widely dispersed areas. The realization of high-speed, very large scale integrated circuit packet switches will open a new era of terrestrial systems in which dynamic packet switching could replace hierarchical switching. We already see new signal and data systems such as ISDN and new protocols for handling packet-switched data and voice transmission.

Communication satellites must be complementary to such terrestrial switching system developments in the future by being able to operate as a "switchboard in space" which can serve specialized data networks in which the switch is in space and not on the ground as presently configured. A switching satellite will operate as a space interconnect node that avoids passing through many terrestrial nodes and avoids the costly local interconnections between users and switches.

As this new generation of satellites, with on-board switching, multiple spot beams, and more powerful transmitters and large antennas comes into operation, it will be possible, in the satellite, to establish "mesh" networks of directly connected very small aperture terminals. Unlike the present "star" networks of small terminals, connections will be made without the necessity of a two-hop transmission via a large central ground relay station. The use of very small aperture terminals will undergo an explosion in growth. This, in turn, will open up services to new communities, such as third world and developing nations, which are currently deprived of a communications infrastructure, and will set the stage for other entrepreneurial exploitations of this enhanced, flexible, ground and space communications capability. All of these developments can reasonably be expected in the second stage; bringing them about will require an orchestrated multistep approach.

This approach will be based on the development and exploitation in experimental systems of three generic classes of technology in order to reduce the costs and risks to U.S. industry in making the transition to operational versions:

Electronic/optical components — high-speed digital devices, circuits and systems for on-board processing and switching;

Microwave and optical components — active and passive devices for forming multiple beams for beam switching, and for efficient high-power transmitters;

Large apertures — antenna and feed systems for creating small-diameter ground spots and high, effective radiated powers.

In-Orbit Switched Service. As a first step, it will be necessary to demonstrate in orbit flexible, dynamic, moderate-capacity voice circuit-switching among synchronized, steerable narrow beams at some minimum level sufficient to provide confidence in the feasibility of the system concept. This step should be accomplished in the next 3 to 4 years and will be the equivalent of the Syncom I demonstration in its relationship to the eventual full development of high-capacity, switched, multiple-narrow-beam systems.

In order to lay the groundwork for U.S. commercial exploitation, a second developmental step will be necessary, one that goes beyond a demonstration of system feasibility and resolves major uncertainties about realizing these service capabilities on a scale near to commercial feasibility. This second step should incorporate a demonstration of the operating system concept at the level of 30,000 switched circuits or more in order to approximate the traffic handling capacity of a contemporary terrestrial level-5 switching system.

Mobile Service. Service to mobile users will begin with the straightforward single or dual beam L-band systems now under serious consideration for demonstration in a joint industry-NASA program. It will be necessary, in the future, to proceed to a second demonstration system employing very large aperture, multiple-beam antennas for frequency reuse in order to exploit fully the limited bandwidth available at L-band. This second step will advance the 10-meter aperture technology of the AST-6 (advanced technology satellite) by demonstration in orbit of a 30-55 meter aperture capability. This demonstration system will resolve questions about interactions of a large antenna with the host spacecraft and will exploit multiple-beam radio-frequency circuit capabilities for beam steering and frequency reuse.

As communication satellite systems reach their full development in the second stage, both fixed and mobile services will be forced to the limits of technology in exploiting frequency reuse and satellite crosslinking techniques to make maximum use of the limited spectrum available in the current operating bands (L-band, C-band, K_u-band and K_a-band).

Accordingly, plans must be made to make the transition to a third stage which, we anticipate, will be revolutionary in concept and technology. The revolutionary concepts will be enabled by technology which will be the result of research and development during the second stage. A strong technology program must be an integral part of the national communication satellite planning process. Further, a certain portion of this effort should be used to encourage unfettered research—of the sort that has typified many technological breakthroughs.

The Third Stage

The third stage in communication satellite services will begin to develop well into the next century and is harder to discern, primarily because the enabling technologies have yet to be developed. Further, inventions in related fields, such as low-cost propulsion techniques, will offer opportunities for new concepts in system deployment and operation.

In this era, purveyors of fixed and mobile satellite services to the developed western world as well as to the expanding Asian, Latin American, and African economies will be striving to keep up with the ever-increasing demand for more bandwidth. It is easy to imagine services such as proliferated high-definition television transmission, or perhaps even holographic image transmission, as examples that will be demanding of system capacity. Beyond the expansion in ground-oriented services, satellites will be supplying communications among the growing population of industrial activities in orbit and, perhaps, at lunar facilities. They could even be relaying high data rate information at interplanetary distances from exploratory bases. At this point, there may be little distinction between the communications technology needed to meet NASA's future needs in lunar and planetary science and space station operations and those of the U.S. industrial space community at large. Thus, it is possible to develop the technology to serve both communities in a single coherent program that will provide increased benefits for a given expenditure of national resources.

In response to the need for these new services, and to the saturation of the available spectrum, satellite systems will be moving up in frequency to quasi-optical (mm-wave) and optical wavelengths. To take the best advantage of these bands, satellite systems may of necessity be deployed in unconventional orbits that allow high look angles from ground terminals.

Third World Concerns

The development of communication satellite services through these stages must also take into account the frequently expressed international concerns about orbit arc and spectrum resource limitations. These concerns have deep political roots and have the potential for serious conflict with concerned third world nations. We believe they will be substantially alleviated if the guidelines proposed here are followed in the development of NASA's Strategic Plan for Space Communications. The technical avenues proposed for exploration are the same ones that will provide opportunity for a large multiplication in the effective use of the orbit arc and spectrum resource, to the benefit of all.

In review, then, we can see three technology plateaus in the overall development of the communication satellite industry. Each may be thought of as requiring a sharp initial ascent, followed by a long, slow climb toward full exploitation. The sharp ascent period involves the greatest technical and financial risk and this is the phase of technology development where the government can best contribute. An historical example is seen in the fundamental early work by NASA in developing Syncom I and the ATS series. This foundation permitted industry to proceed with confidence toward the commercial exploitation that produced our current systems. As we now approach the culmination of the first stage, it is appropriate to prepare a plan that lays the foundation for development of future stages.

NASA's plan should support the national objective of maintaining U.S. preeminence in providing commercial communication satellite services to the world. The goal of the NASA plan should be the timely development of system concepts and technology, for both ground and space elements, that support the national objective. In pursuit of this goal, the plan should follow these major themes, for which we propose programmatic guidelines.

1. Establish and maintain a commanding lead in the three generic satellite technology areas crucial to advancing communication satellite systems:
    - High-speed digital devices, circuits, and systems
    - Microwave devices and circuits
    - Large-aperture antennas and feed systems

2. Exploit this lead through the development of: (a) satellite systems that provide high-capacity, on-orbit, switched service with worldwide connectivity to small terminals; (b) mobile service satellite systems employing multiple frequency reuse techniques that make maximum use of the limited available bandwidth.
3. Develop experimental satellite programs to exploit the technologies, foster new applications, and reduce some of the risk for U.S. industry in the transition to those new applications.
4. Steadily sponsor basic research and development to create an environment for sustaining technological breakthroughs in novel areas such as quasi-optical (mm-wave) and optical communications techniques.
5. Develop the technology that can expand the utility of orbit-arc and spectrum communications resources manyfold. With this technical base, monitor, analyze, and develop government positions for the allocation of these resources among the nations of the world.
6. Assess NASA's future internal operating needs for advanced space communications technology and, where the technology is common to future commercial satellite operational needs, support it as part of the space applications technology development program. The assessment should be made across all of NASA's activities, including the space station, data relay, planetary, and earth observation programs.

Programmatic Guidelines

1. Proceed with the Advanced Communications Technology Satellite (ACTS) program as rapidly as possible. This is a necessary first step; when launched in 1990, it will provide industry experimenters the first opportunity to work with the new generation of communication satellite systems. In addition to industry, government agencies can also take advantage of the opportunity that the ACTS program presents to develop new kinds of communication services. The ACTS program should include the development of sets of representative ground terminals that can be made available for experimental users.
2. Proceed with the program in mobile satellite communications with the objective of a first launch in 1991. The recent Federal Communications Commission ruling allowing commercial operation of mobile satellite systems at L-band provides an excellent opportunity for a cooperative program between industry and government. This opportunity should not be missed. While this first system will be fairly simple (one or two large antenna beams), this first deployment will, again, allow operators to develop simple ground-mobile terminals and to gain early experience with a new class of system.

3. Begin, in 1988, development of the next level of technology for on-orbit, switched systems. These efforts should be aimed at extending the ACTS technology in terms of: multiple antenna beams (one hundred to several hundred); high-speed parallel demodulation; satellite-based control of circuit switching functions at a switching level of multi-thousand circuits; frequency reuse of 25 to 100 times; incorporation of embedded computation capability and data base accessing. This technology should be developed on a time scale consistent with an in-orbit demonstration of the extended ACTS capability in the post-1995 period.

4. Mobile service will realize its eventual full potential through the development of technology for extensive frequency reuse (20 times) at L-band. This will entail large apertures and complex antenna feed assemblies as well as the development of affordable, sophisticated, ground terminals which actively cooperate with the space system in promoting frequency reuse. The technology program in support of these capabilities should be initiated by 1988 with a view toward an in-orbit service capability by 1997.

   By the mid- to late 1990s, it will probably be necessary to consider extending mobile service to the higher frequencies in anticipation of extensive growth in this service, which will saturate the available L-band spectrum. To this end, it would be appropriate to begin development of system concepts for higher frequency mobile service in 1990 so as to define the key technologies that must be pursued for eventual application in the post-2000 time frame.

5. In the more distant future, the satellite communications industry will have to provide entirely new systems, subsystems, and components to satisfy the need for transmission rates that are barely imaginable now. Commercial operations in earth orbit and elsewhere in space, together with as-yet undefined entertainment, educational, personal communication, and remote control applications, will potentially demand extremely wide bandwidths in the twenty-first century. These new services are likely best provided at quasi-optical and optical wavelengths. When this will occur is uncertain, and, therefore, the need to explore technologies pertinent to these eventual services may not appear to be pressing. Preliminary exploration might be reasonably targeted for the late 1990s. However, an early version of similar services is likely to emerge as a requirement in meeting NASA's internal communication needs relating to space station operations, free flyers, data relay, earth resource readout, and planetary probes. Thus, it would be opportune in the near future to begin the investigation of these technologies as part of NASA's program to develop communications technology for space applications. Early exploration should be initiated by 1988.

Other Observations

All these major advances in the delivery of new communications services must be pursued against a background of continued development in the more prosaic subsystem support technologies: batteries, solar cells, on-orbit propulsion, eventual repairability in orbit; more compact, lighter, more capable digital and RF circuitry—all this with the goal of driving down the cost of these subsystems that support the final service.

The cost of launching spacecraft into orbit is the overwhelming determinant of the final cost of space systems. Launch costs per pound of spacecraft are so large that they require extraordinary expenditures in component design, subsystem redundancy, and spacecraft testing to ensure proper spacecraft operation as a hedge against loss of the large investment in launch costs. If communication satellite systems of the sort we envisage are to be realized, lower cost launch systems must be developed. After a long hiatus in launch vehicle development, it is encouraging to see a revived interest on the part of the U.S. government in the development of technology aimed at reducing launch costs. These efforts should be pursued vigorously.

Conclusion

This report proposes ambitious guidelines for the development of communication satellite technology. The committee is aware that many of the long-term objectives proposed are well beyond current NASA programs or the thinking of the existing communication satellite industry. We propose these guidelines because it is our belief that there is great potential for communication satellites to have a critical impact on the future of the information industry, which is rapidly becoming a primary determinant of U.S. international economic strength.

Footnotes

[1]National Aeronautics and Space Administration Authorization Act, Calendar No. 166, Report 98–108, 98th Congress, 1st Session.

[2]National Telecommunications and Information Administration, U.S. Dept. of Commerce, 1986. This estimate does not include electronic mass media distribution services. If these are included, the 1990 world estimate would exceed $1 trillion.

[3]*Economist*, November 23, 1985, p. 6.

[4]Louis Branscomb, "Information: The Ultimate Frontier," *Science*, Vol. 203, p. 143(5), January 12, 1979.

[5]"Pioneering the Space Frontier," The Report of the National Commission on Space, p. 165 (May 1986).

[6]National Aeronautics and Space Administration Authorization Act, Calendar No. 166, Report 98–108, 98th Congress, 1st Session.

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