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ABSTRACT

This report of the Committee on Satellite Communications (COSC) reviews a number of future communication needs which could be satisfied by satellite systems, including needs in fields such as education, health care delivery, hazard warning, navigation aids, search and rescue, electronic mail delivery, time and frequency dissemination, and geophysical exploration. To make such systems possible, technological advances in multibeam spacecraft antennas, low cost earth stations, large satellite power systems, high speed spacecraft communications switches, and spacecraft supporting technology may be required. The committee concluded that the technology to meet such needs is often not provided by the private sector because of the technical and cost risks involved, and therefore suggests that there is an appropriate federal role, and that NASA should resume the research and development activities needed to provide the new technology. (Author/JEG)

Federal Research and Development for Satellite Communications

Committee on Satellite Communications

Space Applications Board

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Report of the
COMMITTEE ON SATELLITE COMMUNICATIONS
of the
SPACE APPLICATIONS BOARD
ASSEMBLY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

FEDERAL RESEARCH AND DEVELOPMENT FOR SATELLITE COMMUNICATIONS

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NOTICE

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee reponsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by the Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

In January 1973, the National Aeronautics and Space Administration (NASA), faced with the necessity of reducing expenditures, examined its programs to determine what could be eliminated. While NASA made a number of reductions, one of interest to this study was the decision to essentially eliminate its satellite communications activities because this was felt to be a relatively mature field and NASA believed that R&D in support of future activities could be provided by the communications industry. Since January 1973, several organizations have assessed the consequences of that decision and have urged that the decision be re-examined.[1]

In late 1975 NASA asked and the National Research Council agreed to study further the question "Should federal research and development on satellite communications be resumed and, if so, what is the proper federal role in this field?" To undertake the study, a Committee on Satellite Communications (COSC) was formed under the auspices of the Space Applications Board (SAB). This report presents the Committee's findings; significant background information and working papers assembled by the Committee during its deliberations will be published separately.[2]

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1 "The Federal Role in Communications Satellite R&D," American Institute of Aeronautics and Astronautics, New York City, 1975; "The NASA R&D Program on Satellite Communications," A Position Paper of the Satellite Telecommunications Section, Communications and Industrial Electronics Division, Electronic Industries Association and the Government Products Division, Electronics Industries Association, Washington, D.C., 1974; untitled paper, Aerospace and Electronic Systems Group, The Institute of Electrical and Electronic Engineers, Inc., Washington, D.C., 1976.

2 Federal Research and Development for Satellite Communications: Working Papers. Committee on Satellite Communications of the Space Applications Board, National Research Council. National Academy of Sciences, Washington, D.C., 1977.

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INTRODUCTION

In the one hundred years since the invention of the telephone, telecommunications has become a pervasive part of the developed world. The telephone is in nearly every home and in every office in the United States, and there is about one telephone for every ten persons on earth. Radio broadcasting and other radio links have become commonplace tools for providing both entertainment and services. Television provides entertainment, news, and educational services to most homes in the technologically developed countries of the world. There remain, however, some troubling limitations to further improvements in communications services. For example, the cost of providing telephone or TV service by conventional means is high in remote and sparsely populated regions. Thus, the Rural Electrification Administration has made and guaranteed about $650 million in federal loans annually to stimulate an extensive rural telephone service now serving 3.1 million subscribers in 47 states.

High frequency radio is widely used to span great distances but suffers from outages caused by solar disturbances of the ionosphere. As a result, ships and aircraft are frequently out of communication with their bases for long periods or during critical phases of their journeys. High frequency radio is also severely spectrum-limited and its use is largely confined to the provision of voice and low-speed data services. First steps in improving ship communications began in 1976 with the launch of COMSAT General's MARISAT satellites which now provide urgently needed, reliable services to U.S. Navy and commercial ships in the Atlantic and Pacific Ocean basins.

Nineteen years ago when the first satellites were launched, it was clear that they could serve as high-altitude relay stations and thus overcome some of the limitations of terrestrial communications systems. First efforts involved bouncing radio signals from orbiting balloons and even from earth's natural satellite, the moon. Another approach involved the use of a receiver-transmitter, called a transponder, in a satellite to relay signals from one distant point on earth to another. Early efforts using low-altitude satellites showed the feasibility of the transponder technique, but such satellites had short orbital periods, did not remain within sight of the earth stations at all times, and required that earth stations continuously track those satellites in view.

The promise of communications via satellite was realized with the use of satellites in geostationary orbits at an altitude of 36,000 km. At that height, the orbit period, synchronized with the earth's rotation, places the satellite in an essentially stationary position above a selected point on the equator and within line-of-sight of about one-third of the earth's surface. This possibility for providing continuity of service and solving the tracking problem was pointed out by Arthur Clarke[1] in 1945 and first achieved by NASA's SYNCOM in 1963.

In 1963, the U.S. Congress established the Communications Satellite Corporation (COMSAT) to bring about a commercial international satellite communications system as quickly as possible and to represent the U.S. in the International Telecommunications Satellite Organization. International satellite communications service began in 1965 with INTELSAT I which could carry 240 telephone channels or one TV channel. INTELSAT II, III, IV, and IVA satellites were added in subsequent years. As of January 1977, the system provides telephone and TV links between the 94 countries that share in ownership of the system. There are also 13 non-owner countries that use the INTELSAT system.

Use of satellites for domestic communications within the U.S. was delayed by political and regulatory processes until 1974 when policy decisions were made about who would provide such services. Meanwhile, Canada's ANIK satellite system had become operational in early 1973, supplying some U.S. domestic services. Since then, a number of companies have entered the field and today satellites are being used to provide domestic telephone or TV services. Additional domestic satellites are planned for the U.S. and for other countries.

Since 1963, the United States has led the world in satellite communications. Initial experiments were conducted by the National Aeronautics and Space Administration and the Department of Defense. Transition from experimental to practical use of satellites was rapid for transoceanic telephone and TV services because there existed an infrastructure ready to exploit this new medium and because the number of new undersea cables was unable to keep pace with the demand. U.S. aerospace and electronic industries were able to capitalize on their own work as well as on the research and development funded in these industries by the federal government to develop a competitive advantage in the world market.

The private sector has continued to make advances in the technology for providing conventional telephone and TV services. The industry has taken some risks; for example, one company paid for launch vehicle improvements and incorporated much advanced technology, not previously proven in flight, in its satellite to improve performance. However, it became clear that the risk the private sector was willing (or could permit itself) to take was limited and that most private initiatives were being channelled to existing markets and to where technical risks were not perceived as unacceptably high. It is clear that even in the largest companies, prudent management requires that large investments in R&D not be made unless there is reasonable assurance that relatively short term payoffs will result. Furthermore, the risk of violating federal anti-trust and trade regulation statutes has led companies to refrain from entering into joint efforts that might permit them to share risk. As a result, following the withdrawal of the federal government from satellite communication R&D, there have been no commercial experimental satellites to test new techniques and concepts or to permit users to experiment with new services.

There are a number of potential communications services, such as for health care delivery, educational services, search and rescue, electronic mail, teleconferencing, and environmental data collection, which apparently cannot readily

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1 Clarke, A.C. "Extraterrestrial Relays," Wireless World. October, 1945, pp. 305-308.

or economically be provided using the technology available to the common carriers for producing conventional telephone and television services. If the option to initiate some of these services is to remain open in the *future*, then advances must be made in needed technology by undertaking research and development programs *now*.

There are examples of work which must be undertaken if new services are to be contemplated. These include technology for utilizing new portions of the radio frequency spectrum, employing larger and more sophisticated spacecraft antennas, utilizing a satellite as a switchboard in space, and advancing technology to drive down the cost of communications.

As time passed, many concerned with the development and the future of satellite communications came to realize that NASA's 1973 decision to reduce R&D in the field might indeed close options if advancements in technology such as those just cited did not become available. Mindful of this, NASA, in the fall of 1975, asked the NRC to conduct a study of the federal role in satellite communications research and development. The NRC agreed on October 7, 1975, to undertake the study and decided that the work should be done by a new Committee on Satellite Communications (COSC) under the NRC's Space Applications Board. It was also agreed that the Committee should be constituted of technologists, communications system operators, satellite communications users, a communications policy specialist, and a regulatory economist. The members were selected with due regard for a balance in viewpoints. Their names and affiliations are listed inside the front cover of this report.

In its work, the Committee considered whether it is likely that satellites in geostationary orbits could make voice, video, and data communications attractive for a variety of public uses not presently provided. Such satellite systems should be able to provide new services to remote and distant places and to sparsely distributed users. For example, using the ATS-6 satellite, Brazil has experimented with delivering television broadcasts to some of its isolated populace. The U.S. has experimented with providing health care information and educational services to inhabitants of remote villages in Alaska, Appalachia, and the Rocky Mountain West. When the ATS-6 was withdrawn from such experiments to keep an international commitment to conduct similar demonstrations in India, a number of user groups testified to their need for the replacement satellite which NASA had planned to launch.[1] However, funds to complete and launch the replacement satellite were not appropriated and no individual user or combination of users was able to afford the estimated $45 million to $50 million to launch and operate it. While the cost-effectiveness of any single application of this type by a satellite may be questionable,[2] the use of multi-purpose satellites may open an increasing number of opportunities for public service, government, and commercial uses.

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1 U.S. Senate Committee on Aeronautical and Space Sciences. Hearings on S.3542, A Bill to Authorize Appropriations to the National Aeronautics and Space Administration for Research and Development Relating to the Seventh Applications Technology Satellite, July 23, 1974.

2 See Educational Policy Center, Instructional Television: A Comparative Study of Satellite and Other Delivery Systems. Syracuse Research Corporation, Syracuse, New York, 1976.

Among the non-technical questions confronting the Committee, therefore, were these: Are there a large number of disaggregated, mainly public service users in remote places likely to need and want the capabilities of satellite communications? Is an experimental program, building on the experience of the curtailed ATS-6 experiments, warranted to permit users to evaluate the worth of such services and to demonstrate the market and the costs? If so, what should such a program comprise and what should be the respective roles of the government, the communications industry and the potential public service sector users?

Collectively in Committee meetings and individually outside of those meetings, the members of COSC: (1) reviewed the history and present status of satellite communications, (2) considered a number of important communications service needs expressed by potential users, (3) identified advances in technology required for meeting those needs, (4) judged which of those advances probably would, and which probably would not, be met by the private sector, (5) structured and evaluated several possible NASA roles in the advancement of technology, and (6) decided upon recommendations.

PERCEIVED NEEDS AND REQUIRED TECHNOLOGY

PERCEIVED NEEDS

The government investment in research and development on multi-channel point-to-point satellite communications, which began with the space age and culminated in the formation of the Communications Satellite Corporation, clearly has borne rich dividends for the country. The revenues from this new industry currently exceed $200 million per year and are expanding rapidly. It was only after the Department of Defense (DOD) and NASA had developed the technology and demonstrated its practical use, however, that commercial firms were able to risk operational systems. Today the price of multi-channel point-to-point voice service has dropped to several thousand dollars per channel-year. Both transoceanic and domestic systems are in operation or planned in a large number of countries.

The situation for other classes of long-range satellite communications -- for example, service to mobile platforms (ships and aircraft) or to widely distributed or remote ground locations -- is much less favorable. Most users of such communication terminal installations feel they can afford only modest sized and low-cost antennas. The services so provided might include public activities such as education, mail, environmental monitoring, geophysical exploration, hazard warning, health care delivery, navigation aids, time and frequency dissemination, public safety, search and rescue, or wildlife monitoring.

The U.S. Department of Health, Education and Welfare and NASA have recently conducted experiments in Appalachia, the Rocky Mountain States, Alaska, and Washington State.[1] These experiments were designed to assess the value of service to remote locations and to assess the communications satellite as a means for providing it. For example, using television, voice, and a variety of data signals relayed by ATS-6 (Applications Technology Satellite 6), the experiments delivered health care and education services to thousands of Alaskans living in

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1 Marion H. Johnson, "ATS-6 Impact: A View from the Control Room," National Library of Medicine News. Vol. XXX, No. 10-11, October-November, 1975, pp. 3-7.

areas too remote to reach readily in person or through ground-based communications.[1,2]

These experiments successfully demonstrated the capability to provide diagnostic consultative services between medical professionals and paraprofessionals, transmit and provide consultations on x-rays, and transmit and up-date medical records, all in real-time via satellites. As a result, the Alaska Native Health Board now assigns highest priority to development of the community health aide program and to improving the communications that provide the aides with professional back-up.[3]

The Public Service Satellite Consortium[4] has compiled the needs of numerous current and potential users similar to those portrayed in the Alaska example, but the fact is that most potential users cannot afford current communication service prices, much as the transoceanic point-to-point users could not afford early satellite communications systems before technology advances brought lower prices. If prices could be reduced, an increased market for such services might well develop.

REQUIRED TECHNOLOGY

The technical challenge in reducing costs for satellite service to small terminals is difficult, but it is no greater than that faced in originating satellite communications in 1958. The basic approach already can be envisioned.[5] To enable small antennas to be used at earth terminals, high-gain satellite antennas must be employed. To be economical, these must be shared by large numbers of users at many locations. Many antenna beams from a single satellite will

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1 Charles Brady, "Telemedicine Moves North to Alaska," National Library of Medicine News. Vol. XXX, No. 10-11, October-November, 1975, pp. 7-10.

2 Martha R. Wilson and Charles Brady, "Health Care in Alaska Via Satellite," AIAA Conference on Communication Satellites for Health/Education Applications, AIAA Paper 75-898, New York, 1975.

3 Subcommittee on Appropriations for the Department of the Interior and Related Agencies, U.S. House of Representatives. Testimony on behalf of the Alaska Native Health Board by Lillie H. McGarvey, May 13, 1975.

4 The Public Service Satellite Consortium is a private organization dedicated to aggregating the public services satellite market. Its subscribers number more than 65 state, local and regional organizations currently conducting over 20 public service satellite communications experiments with the NASA ATS-series satellites and the NASA/Canadian Communications Technology Satellite.

5 Walter E. Morrow, "Current and Future Communications Satellite Technology," Presentation to the International Astronautical Federation 26th Congress, Lisbon, September 1975.

be required, along with methods for accurately aiming the antenna and a means for switching signals from one beam to another by means of a switching system aboard the satellite.

High Gain Spacecraft Antennas

The possibility of high gain (large) spacecraft antennas seems antithetical to the notion of spacecraft weighing, at most, a few thousand kilograms. (The standard 25-meter ground antennas weigh hundreds of thousands of kilograms.) There is one large difference, however, between the surface of the earth and space; namely, in the absence of gravity and wind forces, large space antennas can be built using very light structures.

The NASA ATS-6 spacecraft incorporates a 10-meter parabolic antenna that weighs less than 100 kg and is operable to 10 GHz. This antenna consists of a series of sheet aluminum ribs on which is stretched a metallized net. During launch, the antenna is packed into a small container by wrapping the ribs and mesh around a central hub. Upon reaching orbit, the ribs are released whereupon they unwind into their deployed position.[1] Other designs need investigation with the objectives of further reducing weight, increasing performance, and increasing size.

Multiple Beams

One difficulty with high gain spacecraft antennas is that they produce very narrow beams and therefore have limited coverage on the earth's surface. For instance, the ATS-6 10-meter antenna has a beamwidth of about 1° at one of the operating frequencies, 2.6 GHz. If such an antenna is to be usefully employed over the earth's surface visible to the satellite, it will be necessary to generate a total of about seventy-five beams and to share the spacecraft antenna aperture among these many beams.

As an example, the Massachusetts Institute of Technology's Lincoln Laboratory developed a 10 GHz lens antenna about 0.75 meter in diameter, illuminated by 19 feed horns and producing 19 beams -- which in the case of this antenna will just cover that part of the earth visible from geostationary orbit. The satellite transmitter can be connected by command to any combination of the feed horns. The entire antenna system weighs less than 20 kg. Similar arrangements might be made for large parabolic reflector antennas. In that case, a cluster of antenna feeds would be located at the focus of the parabola. Further development of these concepts is needed both to achieve the proper performance over the required bandwidth and to minimize effects of the space environment such as extremes of temperature.

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1 Computer Sciences Corporation. NASA Compendium of Satellite Communications Programs. Report of Work on Contracts NAS 5-24011 and NAS 5-24012. Computer Sciences Corporation, Silver Spring, Maryland, 1975, pp. 13-59 to 13-81.

Precision Antenna Aiming

With today's technology, aiming an antenna in space to a precision of 0.1° is relatively easy. However, the high gain antennas of anticipated future spacecraft will have beamwidths of 0.1° to 0.5° and will require a pointing precision of 0.01° or better. It is advantageous to attach the antenna rigidly to the spacecraft and aim the structure as a whole. To point the beam accurately, the satellite's location in space must be known, the directional vector to the earth determined, and then pitch, roll and yaw maneuvers performed. The spacecraft location can be determined by means of a series of ground-based observations of satellite range and range rate or by means of an on-board sensor system. One on-board system, in a Lincoln Experimental Satellite, used a precision chronometer and visual and/or infrared sightings of the sun and the earth's edge. The satellite location was determined by noting the time at which the observed angle between the sun and earth reached a given value.

A spacecraft with a large antenna can be turned in space by means of an on-board momentum wheel or wheels. By speeding up or slowing down the wheel, pitch maneuvers can be made. Pivoting of the wheel axis can produce roll and yaw motions. The spacecraft must also be kept in proper orbital position. This is often accomplished by hydrazine-fueled thrusters. Ammonia thruster systems can also be used and electronically powered thrusters have been considered. Current aiming techniques need to be improved and additional research and development initiated to provide simple and accurate systems.

On-Board Message Switching

The use of multiple beam high-gain satellite antennas will permit the use of small terminals. On the other hand, the problem remains of how to interconnect users on different beams. One solution would be to collect the signals from the various beams and transmit them on a very wide-band downlink to a large ground terminal. The interconnection could then be made by conventional switching equipment and the signals returned to the spacecraft on a wide-band link with each signal addressed to the proper downlink beam. This solution, while permitting the complex switching equipment to be located on the ground, would require additional very wide-band channels in the already crowded radio frequency spectrum. Much more power would be required in the satellite and the existing 0.25 second time delay would be doubled.

Another solution would be to perform the switching in the satellite. On-board switching can be done in several ways. While switching at radio frequency would avoid the complexity of demodulation, time sharing in the use of the downlink transmitter would be very difficult.

An alternative is demodulation of the up-coming signals to identify on which beam the down-going signals must be placed to reach the intended recipients. Recent advances in high-speed digital signal processors offer encouragement that on-board switching is possible. Much research and development is needed to arrive at practical solutions and experimental verification in flight will be necessary before the communications industry can risk operational use.

Higher Satellite Power

A way to increase satellite capacity or achieve a given capacity with low cost ground stations is to increase the satellite transmitter power. The transmitter power output is the product of the available prime power and the efficiency of the transmitters.

There is relatively little possibility of increasing the 60% efficiency of current satellite solid-state transmitters operating at frequencies up to 2.0 GHz. At frequencies above 2.0 GHz, travelling wave tubes with efficiencies of up to 40% are commonly used and improvements in efficiency should be possible.

Significant advances in the performance of prime power systems should be possible. Most current satellites employ silicon solar cell power systems having efficiencies as low as 10%. The lightest weight arrangement involves solar-oriented planar arrays having about 20 watts of power per kilogram. New designs having more efficient cells on lightweight flexible substrates should be able to produce 50 watts per kilogram.

It may also be possible to develop even higher power per unit weight by means of larger solar array structures or deployed parabolic solar concentrators which could be used with either solar cells or perhaps Brayton closed-cycle turbo-alternators. These means for achieving larger satellite capacities and thus lower earth station costs require new technology in prime power devices, in structural efficiency, and in the high power transmitter devices themselves.

Modulation Systems

Most contemporary systems employ analog frequency modulation voice and TV transmission. For FM voice systems, a 50 dB power signal-to-noise ratio in a one-cycle band is required. Digital speech transmission systems operating at 2400 bits per second with very efficient modulation systems have been demonstrated to operate at power signal-to-noise ratios of about 40 dB. While currently these digital systems are far too costly to be used in inexpensive mobile terminals, recent advances in the reduction of the cost of digital equipment indicate the possibility of low-cost voice systems operating at significantly lower signal-to-noise ratios.

OTHER TECHNOLOGY AND PHENOMENOLOGY

Other improvements are needed in satellite support systems. Typical of these needs are those for lighter, longer life (nickel-hydrogen) batteries and station-keeping engines (ion engines). Better understanding is also needed of certain space phenomena such as static discharges at geostationary orbit and the effects of rain on the polarization of radio signals. It should be noted that AT&T's COMSTAR satellite carries radio propagation experiments at 18 GHz and 30 GHz. These experiments, although singular, are typical of the many experiments needed to better understand potentially limiting natural phenomena.

POSSIBLE FEDERAL ROLES

The Committee readily concluded that there is no appropriate role for the federal government in providing services that could be furnished by the private common carrier industry. However, the Committee recognized many new public services not yet demonstrated to users or sufficiently aggregated to be perceived by industry as a viable market. As the discussions proceeded, there was an increased understanding and respect for the potential benefits to various public service systems from the use of satellite communications. There was also an increased appreciation that many of the technological advances discussed above and needed to provide these public services were unlikely to come into being in the private sector, especially in view of the perception of unreasonable risk, unfavorable market analyses, or expectation that public sector users will have small budgets. There could be, then, an appropriate federal role -- not in providing services but in undertaking technological advances and in demonstrating techniques that would permit the private sector to expand into new and profitable uses not now contemplated.

Regarding a potentially expanded federal role in satellite communications research and development, two major concerns emerged. The first was the difficulty often experienced by successful experimental programs in achieving the institutional and financial support necessary to effect the transfer from experimental to operational status. Such support is particularly difficult to obtain if the activity falls (as do many of the envisioned public services) within the interest of more than one federal agency. The second concern was how to make sure that after the period of experiment and demonstration necessary to aggregate the market, the government does not continue to provide, on an operational basis, communication services which could be purchased from the private sector. These concerns, of themselves, might bring about the need for strong institutional processes. Institutional concerns were investigated and options for solutions proposed in the reports resulting from the SAB's 1974 study of the practical applications of space systems.[1]

Another concern became evident. The large number of potential new public services, the requirement for ranking their importance and urgency, and the need

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[1] Space Applications Board. Practical Applications of Space Systems. National Academy of Sciences, Washington, D.C., 1975. Panel on Institutional Arrangements, Space Applications Board. Supporting Paper 10: Report of the Panel on Institutional Arrangements. National Academy of Sciences, Washington, D.C., 1975.

for further identifying the technologies necessary for their pursuit became apparent to the Committee. It was concluded that it would be impractical within any reasonable bounds of time and feasibility for the Committee itself to define and rank even a few specific needs in sufficient detail to be credible. Rather, the Committee concentrated on the development of a number of technical options and processes which would assure, whichever programs were undertaken, that from the very earliest planning stages onward, such programs would be the result of collaborative effort between the technologists and the user community leaders, and that needs would be assessed, appropriate technology requirements defined, and a means of monitoring effectiveness established prior to undertaking any substantial effort by the federal government. The various options considered by the Committee, a suggested decision procedure to be followed if any of the options are to be implemented, and the Committee's recommendations are discussed in the remainder of this report.

OPTIONS

As the Committee deliberations proceeded, and as a few particular possible satellite communications programs were discussed in some detail, it became clear that it would be both more feasible and more useful to consider classes of possible programs rather than to attempt to make a detailed study of each of the programs suggested. This conclusion led the Committee to focus its discussions upon six possible options for a federal role in satellite communications research and development:

1. The current NASA satellite communications program;
2. An expanded NASA satellite communications technology program;
3. A satellite communications technology flight-test support program;
4. An experimental satellite communications technology flight program;
5. An experimental public-service satellite communications system program; and
6. An operational public-service satellite communications system program.

In the following discussions of these options, it will be seen that they are neither mutually exclusive nor hierarchical, they are simply convenient. One can, in fact, well imagine an overall program which would include several of the suggested options.

The Committee's recommendations concerning the various options will be presented in a later chapter. Here the various options are defined and, as neutrally as possible, some of the major arguments for and against each option are presented.

OPTION 1

THE CURRENT NASA SATELLITE COMMUNICATIONS PROGRAM

This option represents a continuation of NASA's current satellite communications program funded at a level of about $10 million per year. In NASA's FY 1976 program, about $5.5 million was for support of the ATS and Communications Technology Satellite (CTS) already in orbit, $2.1 million was for technical advisory support to other federal agencies, such as the Federal Communications Commission (FCC) and the Department of State, and to the Communications Satellite Corporation, as required by the Communications Satellite Act of 1962[1], and about $2.4 million was for the advancement of satellite communications technology.

The main argument in favor of this option is that it is the least-cost option which may permit NASA to meet its present legal obligations in the satellite communications field. The main argument against this option is that it does not advance satellite communications technology in any significant way, principally because the program is too small to provide the needed technology and because the opportunity for needed flight demonstration of new technology prior to its operational use is lacking. Also, some people, both inside and outside of NASA, doubt that this option by itself would really enable NASA to maintain the technical competence it requires in order to be able to fulfill its statutorily imposed technical advisory support role.

OPTION 2

AN EXPANDED NASA SATELLITE COMMUNICATIONS TECHNOLOGY PROGRAM

This option would add to the current NASA satellite communications program additional research and development on communications components and systems for both earth station equipment and spacecraft. Funds for flight testing or demonstration of components, sub-systems or systems would not be included. Between $5 million and $10 million per year would be needed in addition to the $10 million funding suggested for Option 1, thus establishing a total budget level of $15 million to $20 million per year for this option.

This option would permit more development of satellite communications technology than would Option 1. Some of the items whose development might be advanced under this option are lower-cost earth terminals; higher-frequency, higher-power, higher-efficiency solid state devices, and new spacecraft antennas and feed designs.

Under this option, funds would not be provided for the launch vehicles or spacecraft required for flight testing. Flight testing would not be precluded, however, if any equipment developed under this option could be "piggy-backed"

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[1] Under Section 201(b) of Public Law 87-624 (the Communications Satellite Act of 1962), NASA is required to advise the Federal Communications Commission on technical characteristics of the communications satellite system, cooperate with the Communications Satellite Corporation in research and development, and consult with the Communications Satellite Corporation with respect to the technical characteristics of the communications satellite system.

on other flights of NASA, DOD, NOAA, COMSAT, or foreign agencies such as the European Space Agency.

The leading argument for this option is that increased support for the development of satellite communications hardware should provide not only for advancement of technology, but also should help NASA maintain, and possibly improve, its internal technical competence in satellite communications, and thereby increase its ability to provide the technical advisory support required by law.

The arguments against this option are (a) the projected level of funding is probably not sufficient either to advance the development of such needed technologies as on-board communications switching systems or multiple-beam antenna systems, or to develop components directed towards specific satellite communication system applications; and (b) the lack of support for flight tests would hamper both the qualification of components and equipment for space use, and the conduct of research on the space environment relevant to satellite communications systems.

OPTION 3

A SATELLITE COMMUNICATIONS TECHNOLOGY FLIGHT-TEST SUPPORT PROGRAM

Under this option, NASA would provide periodic launches of experimental satellite communications payloads for other government agencies and for the private sector. NASA would provide the launch vehicle, launch services, spacecraft platform, and system integration. The initiating (non-NASA) sponsor would be responsible for the experiment definition and execution. If the experiment were of such size or complexity that it constituted a complete payload by itself, NASA would provide only the launch vehicle, launch services and system integration. The budget for such a program is estimated at $20 million to $25 million per year (providing an average of about one launch per year).

In the Committee's discussions, the question frequently arose as to why, since NASA's withdrawal, the private sector has not done more research and development flight experiments concerning satellite communications equipment and systems. The most common answer was that the costs of launching satellite communications flight experiments were far too high for almost any private organization to afford. It was this point that led to the formulation of an option in which NASA would periodically provide at government expense, launches of experimental communications payloads for the private sector as well as for other government agencies (federal, state, or local).

The establishment of priorities for payloads would be a significant concern in implementing any such flight-test support program. Key factors which would have to be considered include: important and potential benefits of the technologies involved; likelihood of success; likelihood that the public would benefit from the public expenditures required for the program; relative size, weight, complexity, power requirements of the experiments; experience of the proposer; funding available to sponsors for experiments; and status of the development of the experiments.

The main arguments in support of this option are:

a) Commercial firms would have an incentive to invest their own money in flight hardware, thus fostering application of thoroughly tested new research and development program results while minimizing federal spending.

b) The maximum applicability to the user's actual needs should be assured because the user would be assuming a significant share of the overall costs of the experiment and would be responsible for definition of the experiment. This should lead to development of more efficient operational systems (including both ground and space segments), thus benefiting the public in the long term.

c) Experience has shown the need for strong ties between launch vehicle activities and constraints and the development and integration of payloads. A single agency is essential to oversee the payload integration with the launch vehicle, including technical and managerial guidance, support, and scheduling; these functions fit well with NASA's capabilities and experience.

d) NASA has the authority, procedures, arrangements, and interfaces with the various concerned foreign governments for rocket operations over international waters and foreign territories. Lack of such a capability would present a formidable obstacle to any attempt to establish a non-government launch activity to replace NASA in that role.

e) Finally, and perhaps most importantly, NASA is an existing organization. Its staff includes individuals with skills and experience in all of the disciplines needed to plan, organize, and conduct nearly any space flight program.

The main arguments against this option are:

a) The selection process for technology experiments for flight-tests might well become a problem when experiments are proposed by competing commercial ventures. Because of the diverse nature of the participants, it would be difficult to establish, to the satisfaction of all concerned, what advances in technology were needed. Selection of one experiment over another could result in providing an unfair unique advantage to one segment of the competition. For example, the new technology being flight-tested would probably be useful in the near term only to the experiment proposer because only he would have definite system plans for the utilization of the experimental results.

b) Even though orbit locations for experimental satellites usually need not be as severely constrained as is necessary for operational satellites, there will be restrictions on the number of experimental communications satellites which can be in operation at any given time. These restrictions will probably become more severe with the passage of time. Geostationary orbital "parking spaces" within view of the U.S. mainland are being occupied rapidly, predominantly by operational satellites. While use of new frequency bands may permit somewhat closer spacing of satellites, even this measure probably will not relieve the shortage of orbital parking spaces.

c) Because of the high cost of development of complex payloads or entire spacecraft, even with flight-test support, private sector R&D programs may be limited to a very few large corporations. Some important elements of the private sector may not be able to afford investment in experimental spacecraft. In addition, proprietary considerations could and probably would inhibit the dissemination of the experimental results.

d) Because of the private sector's inhibitions on risk-taking, efforts on this option would probably be biased toward conservative advances in technology, rather than composed of a balanced program which included both conservative and risky or long term (but high pay-off) advances.

e) Competitive and proprietary aspects of privately supported experiments could make it difficult to combine the best features of several technically similar, but not identical, proposals into one composite experiment which could be better than any of the singly proposed experiments. Thus, opportunities for synergism resulting from use of the same space hardware for a multi-technology, multi-mission experiment (e.g., the ATS-6 multi-frequency, multi-mission antenna feeds all using the same single large reflector) would be lost.

f) Finally, in view of the use of federal funds to pay for launch costs, it would be difficult to resolve questions such as proprietary rights, disclosure of results, patent protection, and government rights (if any) to new technology.

OPTION 4

AN EXPERIMENTAL SATELLITE COMMUNICATIONS TECHNOLOGY FLIGHT PROGRAM

The objectives of this option are the development of satellite communications and associated spacecraft technology, flight testing of that technology, and the conduct of environmental and propagation experiments in orbit.

NASA would incur the total cost of all aspects of this option, including the cost of satellite payloads; the experiment definition and execution would be the joint responsibility of NASA and the non-NASA proposers of flight experiments. The NASA budget for such an option is estimated at $50 million to $75 million per year.

This option is essentially similar to the Applications Technology Satellite program NASA has been conducting since the mid-1960's using satellites developed prior to 1973. As in the ATS program, the proposed flight experiments (including the required payloads and spacecraft) would be defined by NASA but largely as a result of calls for experiments made to communications common carriers, spacecraft suppliers, subsystem suppliers, not-for-profit technology organizations (including universities), and public and private users of satellite communications systems. A representative committee of knowledgeable people drawn from NASA, industry, universities, and users of the experimental results would be charged with selecting, as objectively as possible, the best combination of flight experiments. For example, important new technologies (such as multi-beam antennas or satellite switchboards) might well be proposed by several different groups. The various separate proposals would then be aggregated into one or more flight experiments which would incorporate the best features of the several proposals and represent a reasonable balance between risk and technical capability payoff. In any case, experiments which could be, and should be, supported by the private sector would not be supported by NASA.

While this option is formulated here in the context of satellite communications, the list of experiments to be supported could also, quite properly, include, for example, some experiments in meteorology, navigation, or earth resources observation satellite systems. The possibility of "piggy-back" satellite communications system experiments, as in the existing ATS-6 program, should also be considered (a) whenever a user community can be identified which is prepared to follow up on the outcomes of the flight experiments, and (b) whenever the estimated marginal costs of a user experiment are improved or at least matched by the estimated marginal benefits.

The main arguments in support of this experimental technology flight program option are:

a) This option would provide the basic elements needed to support both governmental and industrial research and development requirements in the field of satellite communications. Flight test opportunities would be provided, both to industry and to government, assuring timely completion of needed technology projects. Especially important is the continuation of space environmental and propagation research and the exploration of high-risk, high-payoff technologies.

b) By encouraging research, development, and testing of frequency re-use techniques, this option should help solve the problems of rapidly increasing national and international competition for frequencies and geostationary orbit positions. Private enterprise is not likely to invest in the technical research and development required to solve these international allocation problems.

c) This option would help prevent the U.S. losing its competitive position in the communication satellite field to foreign manufacturers that have governmental subsidies. Experience gained in work proposed in this option could help preclude foreign control of the design and manufacture of significant portions of our domestic and international satellite communications facilities.[1]

d) This option would substantially improve NASA expertise in satellite communications and thus better enable NASA to carry out its statutory role to provide technical advisory support to other federal agencies and to COMSAT.

e) The work described under this option falls within NASA's interests and responsibilities in planning and conducting this country's civilian space program.

f) A wide set of knowledgeable proposers could be involved and the best features of several proposed experiments could be combined into composite experiments better than any of the single ones.

g) Spacecraft technology as well as communications payloads could be accommodated, and conservative as well as risky experiments could be included.

The principal arguments against this option are:

a) Direct applicability of experimental flight equipment to operational applications might be minimal and further development would be required by potential users. A transfer mechanism is lacking which would facilitate the moving of experimental products into operating systems.

b) There could be serious risk of payload failure if the space platform contained much new technology.

c) Cost would be higher than earlier options. The same technical objectives might well be accomplished under private funding, if the proper incentives were provided.

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1 The U.S. competitive position regarding small earth stations is discussed in detail in Study of Small Earth Station Markets (United States and Foreign Trade). United States Department of Commerce Report No. S-35628, Arthur D. Little, Inc., Cambridge, Massachusetts, December, 1975.

OPTION 5

AN EXPERIMENTAL PUBLIC SERVICE SATELLITE COMMUNICATIONS SYSTEM PROGRAM

Under this option, NASA and appropriate user agencies would jointly define, develop, and test (including flight demonstrations) new public service satellite communications systems. In addition, NASA and the user would be jointly responsible for transferring the new systems to the appropriate operating agencies. The budget for this option is estimated at $50 million to $100 million per year.

A constantly recurring theme in the Committee deliberations was the concept of a public service satellite communications system. Such a system might, for example, be used in the delivery of health care to remote areas or in the delivery of educational materials to student bodies thinly dispersed over large geographical areas. The example of the experimental use of the ATS-6 satellite communications equipment by the Alaska Area Native Health Service for delivery of health care to remote Alaskan Indian villages was discussed at length in the Committee sessions. This example showed not only how a satellite communication system could aid dramatically in carrying out a public service mission, but also pointed up sharply many of the problems involved in such an application; e.g., the problems of how to initiate, define, implement, and pay for such an experiment, how to make the transition from an experimental system to an operational system, and how to pay for the use of an operational system.

While a consensus developed in the Committee that a number of potential public service systems could clearly benefit from the use of satellite communications, there also arose a very strong view that NASA funding should not be used to provide operational communications capability free of cost to the federal, state or local agencies which benefit from or participate in using satellite communications capability. To do so would obscure the real costs of the public service, and the agencies who have need for and use or provide these services would not be faced with the hard reality of determining whether a program is worthy of execution when compared with its actual cost. Additionally, NASA should not be involved if needed services could be provided by existing satellite assets of the common carriers.

Simultaneous awareness of perceived public service needs and the attendant difficulties of support and transition from experimental to operational status led the Committee to define this public service satellite communications system option. The Committee also proposed a four-phased decision process to be followed in the development of such a system so as to assure appropriate checks against what was seen as the possibility of "hidden subsidy."

The four phases of system development in which the proposed decision process would be applied are:

1. A conceptualization phase involving needs assessments, technology projections, service concept development, and program design;

2. An experimentation phase using NASA-developed and -launched communication satellites in an experimental system including formulation of criteria by which the

experiments will later be judged for acceptability and worthiness for transfer to operational status;

3. An acceptability phase in which the transition to an operational system is initiated and implemented; and

4. An early operational phase.

Depending upon the outcomes of evaluations made in each of the respective phases, any given public service satellite communications program would either be terminated partway through the process or carried on through the entire process. The details of this decision process are discussed in the following chapter.

The main arguments in support of this public service experimental option are:

a) Experience in various departments of the federal government has shown that one of the more difficult parts of any program is the transfer from a developmental organization to an operational organization. Even if highly successful, a demonstration of technical feasibility is seldom sufficient to provide a reasonable expectation of successful transfer. This option assures that adequate priority is given to the demonstration of new use capabilities well beyond mere technical feasibility. Cost accounting and responsibility assignments for evaluation of the programs as they progress would be clear and effective under this option.

b) This option provides a common ground on which potential users and communications technologists can work together to effect a match of needs with capabilities. Historically, needs remain unmet when capabilities are not known and capabilities remain undeveloped when needs are not known.

c) Enough users could be assembled to decrease the cost of using the system to each and increase the probability of obtaining useful results. Capabilities are often not exploited by individual users because of high costs and costs remain high because of lack of use. This option would identify the areas of greatest potential return and allow attention to focus upon reducing costs in those areas.

The main arguments against this option are:

a) This option assumes that the potential beneficiaries, suppliers, and payers can be identified, an assumption which might tend to favor applications that can be implemented comparably well by existing facilities, if only appropriate institutional changes are made. Thus, novel and unexpected applications might not be developed because their utility was never demonstrated.

b) If, in fact, the strongest justification for public programs is that institutional barriers seem to be too high to permit providing the services by the private sector, it might be better to work on the institutional barriers than to duplicate private with public facilities.

c) The real costs of many government programs tend to be hidden and not understood by some segments of the potential user community. This could lead to false expectations for low-cost service. For example, in the ATS-6 demonstration service to Alaska, Native Health Service officials understood that the satellite was NASA-furnished and the ground station installation costs were paid by the federal Department of Health, Education and Welfare. The general public's perception of these financial contributions was, however, less well formed.

d) Inertia alone could tend to sustain some experiments. A program might be continued for the sake of its own survival, even if it became apparent that its content was of questionable value in the satisfaction of public service needs.

e) The problem of obtaining decisions, cooperation, and long-term commitments from several federal agencies which might be involved in a program could make institutional arrangements so difficult as to make this option infeasil

f) Proof of cost effectiveness and aggregation of users may be difficult in advance of user demonstrations. This could stifle or delay introduction of promising new capabilities.

g) Cost could be higher than earlier options.

OPTION 6

AN OPERATIONAL PUBLIC SERVICE SATELLITE COMMUNICATIONS SYSTEM PROGRAM

Under this option, NASA would provide and operate a public service satellite communications system. Funding options could range from total federal subsidy to total user reimbursement for services rendered.

Option 5 progresses from a public service satellite communications experiment through the transition to a non-NASA operational public service system. There remains to be examined the logical extension of Option 5: the possibility of NASA operation of a public service system.

This option would provide a service which is supportive of a national goal or requirement as determined by the Executive Branch or the Congress. The service offered might be in response to a perceived domestic need or it might be part of a worldwide program of assistance to developing nations. It is envisioned that NASA would be the sole operator of the system.

The primary arguments in support of this program option are:

a) Since many public missions (such as education and health care) are presently supplied partly or wholly by the public sector rather than by the private sector, the communications needs of such services should also be provided by the public sector.

b) A single agency would be in a better position than a combination of agencies to aggregate funding and requirements from many sources; NASA has the expertise in design, development, and management of large systems necessary to undertake this task.

The main arguments against this option are:

a) This option is not in conformity with the policy of the Executive Branch (as of this writing) of relying upon the private sector to supply needs, except where it is clearly in the national interest to do otherwise.[1]

b) Even if the government policy referred to above were changed, the use of NASA as the system operator might narrow the consideration of "communications" from a wide perspective into the narrower "satellite communications," to the possible detriment of health, education, and other public service programs which might better be served by competing means.

1 Office of Management and Budget Circular No. A-76 (revised), August 30, 1967.

DECISION CRITERIA

When the time came to consider conclusions and recommendations after defining and discussing the various options, the Committee became concerned about possibly recommending increases in the NASA satellite communications program without, at the same time, providing checks and balances to prevent an indiscriminate expansion of that program. The Committee saw a need to assure that any program which was likely to lead, either directly or indirectly, to the provision of satellite communications services would forcefully take into account from the start the needs of the ultimate user and, in addition, would make full and appropriate utilization of the competencies and resources of the private sector. It was in this context that the Committee proposed the four-phase decision procedure discussed in this section. Although the entire procedure was proposed initially in reference to Option 5, the Committee believes that the first two phases of this proposed procedure should apply as well to Option 4.

While the results of the early NASA program in point-to-point satellite communications technology were transfered rapidly to commercial applications, the later phases of the ATS program, which explored satellite technology suitable for providing public service, did not result in a similarly rapid availabili[illegible] of commercial services. One explanation for the earlier pattern of developm[illegible]t is that the nature of the market for domestic and international point-to-point telephone and television services was well known before the introduction of satellites and the institutional structures required to service and develop this market were already in place. The satellite was simply viewed as another means for delivering existing services, providing a way to reduce costs or to increase service area. The situation with respect to satellite communications designed to provide public services is quite different. Truly equivalent public services do not yet exist, nor do the organizations to provide or utilize such services. The nature of the market is not clear: such potential users as can be identified are quite disaggregated and present a difficult market, especially in the absence of an operational commercial distribution or broadcasting service.

A POSSIBLE TRANSFER MECHANISM

The transfer mechanism needed to make an effective transition of innovative communication satellite technology into the mainstream of operational services is, in fact, a diverse collection of activities including market exploration, technology transfer, institutional development, and regulatory incentive -- all hopefully coordinated by an inspired public policy.

The Committee believes that an effective transfer mechanism should, at a minimum, possess the following attributes:

1. Comprehensiveness

Unlike much previous federal activity in satellite communications, both the equipment and operational aspects of a given service concept must be considered simultaneously. It is essential that those federal agencies concerned with substantive applications of satellite communications to their assigned missions (e.g., health, education, commerce, etc.) be party to developing the transfer strategy and be actively committed to its implementation. The development of the application concept, and its acceptance by end users, is as important to the transfer process as is the development of the technology.

2. Orderliness

Orderly progression from an activity with substantial federal government involvement to one with little or no federal involvement should occur as uncertainties about form, performance, and viability of a given service concept are resolved. The specific approach suggested in this chapter involves a sequence of four phases for this orderly progression. The limits of federal involvement should be carefully specified for each phase. The commercial carrier model is assumed to be the typical long-term communication supplier institution. The institutional form of the user community is unspecified and is assumed to be the subject of experimentation, development, and change.

3. Accountability

The amount of public investment and degree of federal involvement in the development of any specific service concept should be governed by standard investment criteria. However, while the government should not be as risk-averse as commercial firms when considering a potential development (because the government may take a longer-term view or may attach a public service value to the product), it should still be responsible for ascertaining that the value of the services or the technology to be developed justifies the investment being made.

In general, a decision procedure should be adopted that selects projects with attractive potential and that provides regular opportunities for reassessment to limit losses when hypotheses prove wrong. The procedure should not prematurely terminate slow but promising developments. An explicitly sequential decision process offers many advantages in that maximum use can be made of information obtained through experimentation to provide mid-program correction.

4. Continuity

Because the measures of success or failure in process, procedure, and utility to the user are subject to more variation than that of the technical equipment, and because the time involved in institutional change is often substantial, it is important that the evaluation be carried out over appropriate time intervals. (A three-month experiment with ATS-6 may have been adequate to show that the communications system worked properly, but to determine its effects on education might require that it remain in use for a period of several years.)

Establishing feasibility for many uses is greatly influenced by perceptions of the evaluation process and the degree of commitment of the experimenters. For these reasons, the steps of the transfer process must be of appropriate length and there must be a continuing commitment to see each specific program through to its logical conclusion. Success might be measured in a number of ways, the limits being successful transfer to the private communications sector or termination because of failure to meet the established criteria for progression to the next phase of the transfer process.

THE PROPOSED DECISION PROCEDURE

The specific transfer decision process proposed here consists of a series of four coordinated and phased activities. Each may involve a different combination of federal agencies and private organizations and entail a different level of federal investment or intervention. Progression from a federal research and development project to a commercial communication service should be orderly and more or less automatic if, at the conclusion of each phase, the project measures up to certain pre-established criteria. On the other hand, undertakings that do not measure up to expectation within a reasonable period, as determined *a priori* for each specific project plan, are dropped.

Phase 1: Conceptualization

This phase includes assessment of needs, technology projections, service concept development, and program design. Management of this phase should be vested completely with NASA, but specific provision should be made for the participation of a wide range of private and governmental organizations including, in particular, representatives of the likely ultimate users. During this phase, outcomes are highly uncertain, creativity at a premium, interaction dynamics ill-defined, and the relationship of expenditure to end product difficult to establish. It would seem reasonable to establish a base level of effort for this type of work and not tie the decision on overall funding to the acceptance or performance of individual study projects.

Funding should be adequate to ensure a flow of project proposals for Phase 1 greater than are likely to be funded so that there will be some competition and basis for comparison. A fixed small percentage of the space applications budget (say 2% or, at current levels, approximately $5 million per year) should ensure that, despite some risk, proper examination of potentially high payoff concepts is undertaken.

Phase 2: Experimentation

The second phase of the transition process would involve actual experimentation using NASA-developed and -launched communication satellites. The technical design of the experimental communication satellite would be derived from a comprehensive project design (the output of Phase 1) that may support several end user service concepts with a single communications system. The decision to proceed with a flight program would be made on a case-by-case basis and would not be NASA's alone, nor would the management of the resulting overall applications experiment program be entirely NASA's. NASA would, however, be responsible for the satellite and associated ground equipment portions of the project.

Policy guidance for this phase might be provided by a committee consisting of senior officials from the Office of Telecommunications Policy, Executive Office of the President and from mission agencies such as the Veterans Administration, the Department of Health, Education and Welfare, or the Department of Commerce. Participation in an advisory role by the Federal Communications Commission, commercial common carriers, and the private communications industry would be most desirable during this phase to lay the groundwork for Phases 3 and 4.

In the case of Option 5, in which user services are to be demonstrated, no NASA spacecraft development should proceed without a concurrent commitment from one or more of the mission agencies to undertake development of specific operational services designed to capitalize on the unique communications capabilities of the NASA satellite.

The typical Phase 2 project is perceived to be of five to seven years duration with at least two years of operational service development after launch and confirmation of the technology. It is believed that there will be greater risk in Phase 2 with respect to the technology and/or the operational viability than the communications industry and the end users would be able to accept unilaterally. NASA and the federal mission agencies would therefore have to accept this risk on behalf of these communities and the general public. There will have to be contingency plans and some overlap of flight programs -- perhaps one launch every three to four years for programs of seven-year duration -- to provide protection against space segment failure. Technical and operational uncertainties and costs can be significant, and there is a finite possibility of overrun or even a large loss. On the other hand, the potential gain from a well conceived program should be sufficient to justify the cost, as long as each step of the development process continues to meet with success.

In Phase 2, the funding for both the hardware and software aspects would come almost entirely from the federal government but the duration of such federal funding would be strictly defined in advance (e.g., two years after launch the project would qualify for Phase 3 or lose its federal funding).

Phase 3: Viability/Acceptability

This phase of the transition process is critical, and in most past cases it has been neglected. It should occur only after the technology has been proven and the validity of the operational service concept demonstrated. At this stage, proceeding directly with commercial communication service usually would entail more risk than either the commercial carriers or the end user could accept. The problems would be principally those of competitive commercial investment criteria and rate of return on the private sector side and institutional change and rate of acceptance of new approaches on the user side. Full federal subsidy at this point in the transition process is not needed, and could, in fact, be detrimental. The active participation of both the communication industry and the end user organizations through commitment of their own resources (time, facilities, and money) is absolutely essential to Phase 3. Continued federal support for user experiments should be on a decreasing basis. The communication carrier industry's willingness to share the market development costs is also important to the success of the transition concept, and the transition process should not proceed further without that commitment.

During this phase, the project should be managed by a joint government-industry-user committee with chairmanship resting with that organization or group of organizations which has the largest investment in the project (this need not be a federal government agency.) To the maximum extent possible, the communication service should be provided by commercial carriers, perhaps under lease arrangement from the government. In those cases in which NASA experimental satellites developed in Phase 2 are still functioning and suitable for continuing the services, they might be sold or leased to carriers at a reduced cost to permit the carrier to offer the initial service to a smaller number of customers than would be necessary if it had to justify launching a satellite with its own capital.

Special attention should be given in Phase 3 to institutional arrangements that will improve the viability of the proposed service and increase the rate of growth and ease of pursuit of the specialized user market. The Public Service Satellite Consortium is an example of the type of institutional arrangement that the federal government might subsidize as part of Phase 3 activities.

In conclusion, Phase 3 is characterized by low technical risk, modest but declining economic risk, and increasing acceptance of the service concept. Risk-sharing mechanisms, incentives, and private sector management are as important as direct federal funding and management during this phase. Federal agencies such as the Department of Health, Education and Welfare, the Department of Housing and Urban Development, or the Veterans Adminstration, which are closer to the end users should play a stronger role, occasionally acting to aggregate the market or as surrogate for less well organized segments of the user community. Government provision (via NASA) of the complete space segment, including launch, should be a matter of last resort during Phase 3, although NASA may provide equipment to commercial carriers for integration into commercial satellites and may provide various support services on a reimbursable basis.

Phase 4: Early Operational

During this phase, the service or services are offered commercially but may not yet be fully self-sustaining in a profit sense. In addition, some institutional change may be needed either from the user or the carrier point of view to develop a viable market, and it may be in the long-term public interest to subsidize this change. Regulatory incentives, as well as guaranteed purchase of communication services by the government for its own use, would be the main form of federal support during Phase 4. The OTP might provide policy guidance for Executive Branch purchase of communications services and the FCC could establish the regulatory incentives to help new services develop. In addition, continued federal support for various user groups who utilize various operational social services could be considered.

FUNDING

A final word is in order concerning reasonable federal funding levels for the various phases of transition. Phase 1 is seen as a continuous NASA activity which might run $2 million to $5 million per year. Each Phase 2 project might represent a total federal expenditure of $150 million to $200 million, including the NASA portion. However, since the individual flight programs are assumed to take from five to seven years to complete, and will only be started once every three or four years, the annual outlay per project for Phase 2 would run $35 million to $50 million per year. Because Phase 3 is basically negotiated between industry and government, it is difficult to say what the outlay might be, but it is believed that initially $5 million to $10 million per year for federal communications procurements could provide an important incentive to the carriers to invest their own funds in anticipation of future user orders. Additional federal funds would be necessary in the applications areas to support the user organizations.

Phase 4 costs are not easily definable at this time, but will largely consist of transfer payments and temporary preferential treatment for certain desired classes of services.

CONCLUSIONS AND RECOMMENDATIONS

The Committee, in its deliberations, reviewed a number of future communications needs which potentially could be satisfied by satellite systems. These included needs in fields such as education, health care delivery, hazard warning, navigation aids, search and rescue, electronic mail delivery, time and frequency dissemination, and geophysical exploration. Many of these are public service needs which might be satisfied by satellite communications systems using high power and a high-gain antenna in the space segment, permitting low-gain, low-cost earth stations. To make such systems possible, technological advances in multibeam spacecraft antennas, low-cost earth stations, large satellite power systems, high-speed spacecraft communications switches, and spacecraft supporting technology may be required. If costs can be reduced by the application of new technology, many potential public service users may benefit from new satellite communications services.

The Committee concludes that the technology to meet such needs is often not provided by the private sector because of the technical and cost risks involved. The Committee therefore concludes that there is an appropriate federal role and that NASA should resume the research and development activities needed to provide the new technology, subject to the restrictions discussed in the "Decision Criteria" section.

As discussed earlier in this report, it became clear as the Committee progressed through its deliberations that it would be neither possible, nor appropriate, for a part-time, short-duration committee to undertake an exhaustive study of the future needs of the country in satellite communications and then to make detailed recommendations on the basis of such a comprehensive study. Instead, the Committee focused upon classes of possible NASA programs (called "options" in this report) and, accordingly, the Committee's conclusions and recommendations are focused on the options considered.

The Committee concludes that the current NASA satellite communications program (Option 1) is inadequate, both in terms of meeting NASA's statutory advisory obligations and in terms of meeting the country's needs in satellite communications research and development. Some members, but not all, felt that if this option were the only one that the nation was willing to support, NASA should drop out entirely of the satellite communications research and development business, and that legislation should be sought which would terminate NASA's statutorily mandated advisory responsibilities in satellite communications.

The Committee believes that the extra funding required to support an expanded NASA satellite communications technology program (Option 2) is not likely to produce enough returns of value to the country to make it worthwhile pursuing, and therefore recommends against it.

Option 3, a satellite communications technology flight-test support program, has considerable appeal in that it is directed at removing a major roadblock in the way of increased private sector investment in satellite communications research and development. Such a program would face many difficulties in deciding fairly who should be provided such opportunities and in resolving questions of access to results, patent protection, government rights, and proprietary rights, to name a few. The Committee therefore is skeptical of the likely efficacy of such a program and recommends against pursuing it -- even if undertaken in conjunction with Option 1.

> *The Committee recommends that NASA implement an experimental satellite communications technology flight program (Option 4) using the safeguards provided by the first two phases of the decision process discussed in the preceding section.*

That procedure is intended to ensure that the communications technology program is responsive to the perceived needs of the entire satellite communications community, including, in particular, potential users of the services. In addition, it is believed that following this procedure will help foster better transition of the experimental results into subsequent operational systems.

It seems clear to the Committee that there are a number of potential public service satellite communications systems which should be investigated in detail for possible implementation. However, as discussed in the preceding chapter, the Committee also believes firmly that NASA should pursue such a program only if one or more potential user groups are involved from the start of the program through its finish, and only if the estimated costs and benefits are thoroughly investigated and the balance indicates the pursuit of the program is worthwhile.

> *The Committee recommends that NASA implement an experimental public service satellite communications system program (Option 5), provided that the program is carried out using the entire four-phase decision process discussed in the preceding section.*

The Committee concludes that the arguments against an operational public service satellite communications system program (Option 6) are compelling, that such an option is inappropriate for NASA, and recommends against it.

In summary, the Committee on Satellite Communications concludes that there might well be a number of public service communications needs which satellite communications systems of the future could help satisfy. Some of these services and systems may require the development of technology such as multi-beam spacecraft antennas, low-cost earth stations and on-board signal switching -- technologies which do not readily derive from current or anticipated future activities of the private communications common carriers. In addition, because of the disaggregated nature of those who need these services, the private sector often cannot find a ready market which justifies the risk of expansion into the provision of these new services. There is, then, an appropriate federal role in assisting the development of needed technology and in demonstrating new public services for a sufficient period that their users may be perceived as a viable market by the private sector. The most appropriate supplier of the needed technology is NASA.

> *The Committee recommends that as soon as possible, NASA, with the participation of appropriate user groups, begin conceptual definition of both the needed technology (Option 4) and the public service experiments themselves (Option 5).*

These initiatives are the first steps in the implementation of the Committee's Options 4 and 5 which have been described earlier in this report. The report also describes a process of checks and balances which the Committee believes are essential to channel the expanded NASA role in the needed direction.

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