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A REVIEW OF THE ECONOMIC IMPLICATIONS OF THE NATIONAL ACADEMY OF ENGINEERING 1974 STUDY OF THE POTENTIAL APPLICATION OF SPACE SYSTEMS

ECON INCORPORATED

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FINAL

A REVIEW OF THE ECONOMIC IMPLICATIONS OF THE NATIONAL ACADEMY OF ENGINEERING 1974 STUDY OF THE POTENTIAL APPLICATION OF SPACE SYSTEMS

Prepared for

National Aeronautics and Space Administration

Office of Applications

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September 1975

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NOTE OF TRANSMITTAL

This report was prepared for the National Aeronautics and Space Administration, Office of Applications under Contract NASW-2558. In it we review the National Academy of Engineering Summer Study of 1974 and make recommendations for further, in-depth investigations. As such, the purpose of this document is to serve as a guide for planning the continued study of the economics of applications satellite systems.

ECON acknowledges the contributions of R.J. Christie, G. Fawkes, G. Hazelrigg, K. Lietzke, B.P. Miller and P. Stevenson in the preparation of this report.

Submitted by

B.P. Miller
Study Director

FOREWORD

In 1973-74 the National Academy of Engineering (NAE) conducted a study of the practical applications of space systems for the National Aeronautics and Space Administration. Preliminary findings of the study were made available to the Administrator of NASA in November 1974 in a letter from the Chairman of the National Research Council. The preliminary findings identified many potential applications of space systems for future development. In some cases specific user needs for these systems were identified, while in other cases only a broad concept of user needs could be drawn. Similarly, in some cases an attempt was made to estimate the magnitude of the benefits that could result from the development of the systems while in other cases the benefits were described in a qualitative fashion. In February 1975, ECON, Inc. was requested to perform a review of the economic implications of the NAE study of the Practical Applications of Space Systems. The objectives of the ECON review were to identify areas of potential economic impact in the NAE study, and to describe methods to prioritize the applications areas and estimate the benefits. Since the final report had not been issued, the ECON review was performed using draft reports prepared by the various panels comprising the NAE study group made available during March, April and May 1975.

The review indicated that many of the benefit areas described in the NAE study were supported by economic studies that have recently been completed or are now in process. Where this was the case, a correlation was made between the benefit area and the existing economic studies. On the basis of this correlation, four areas were then selected for in-depth review. Three of these, Communications, Materials Processing in Space, and Institutional Arrangements for Space Applications, were areas in which ECON had not previously performed economic studies. The fourth, Weather and Climate, was an area in which our studies covered one specific aspect of the economics of improved weather forecasts, namely the potential contributions of the SEASAT, SEOS and STORMSAT systems. Each of these four areas were then analyzed to identify the current issues of economic importance to NASA and the methodology that could be used to estimate the benefits and prioritize the applications areas. Thus, each of the four major topical sections of this report contains specific recommendations concerning issues deemed to be of economic importance to the planning and implementation of the NASA program of space applications. While it was considered that recommendations concerning the economic implications of those applications areas that are currently supported by on-going studies would naturally evolve from those studies, recommendations concerning those applications areas where the supporting economic studies have been completed are described. These recommendations can provide a framework for the economic analysis of future space applications programs.

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1.0 INTRODUCTION

The objectives of this study were to identify user benefits resulting from the application of space systems to those application areas described in the 1974 NAE Summer Study,* and to describe methods to prioritize the application areas and quantify the benefits. The major potential benefit areas of space applications identified by the 1974 NAE Summer Study were the following:

- Weather and Climate
- Communications
- Land Use Planning
- Agriculture
- Forest and Rangeland Management
- Inland Water Management
- Extractable Resources Management
- Environment Management
- Marine and Maritime Applications
- Materials Processing in Space
- Institutional Arrangements for Space Applications

In this report, ECON reviews these space application areas and examines the basis for and potential magnitude of the economic benefits that may be realizable from these

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*"Practical Applications of Space Systems" by the National Academy of Sciences, 1975 (draft report).

applications. In addition, we present recommendations concerning studies that should be undertaken to develop a more precise understanding of the source and magnitude of the realizable economic benefits.

2.0 PAST AND CURRENT STUDIES OF THE ECONOMIC BENEFITS OF SPACE APPLICATIONS PERFORMED BY ECON

This section discusses remote sensing benefit estimates developed or reviewed by ECON independent of this report. Three separate types of applications satellite systems have been or are being studied by ECON:

1. The LANDSAT, or LANDSAT-derivative, sensing system: In the summer of 1974, ECON reviewed previous work pertaining to capabilities and benefits obtainable from the ERTS-1 (now LANDSAT-1) satellite and performed case studies where warranted.* This was a broad-brush study looking at economic benefits in the application areas of agriculture, forestry and rangeland management, inland water resources, land use, non-replenishable natural resources, atmosphere, oceans and industry. Currently, in-depth case studies are being performed by ECON to determine economic benefits obtainable from LANDSAT-like systems with varying capabilities in the application areas of U.S. and worldwide crop inven-

*"The Economic Value of Remote Sensing of Earth Resources from Space: An ERTS Overview and the Value of Continuity of Service," ECON, Inc., December 1974.

tories (for wheat, small grains and soybeans),* inland water resources management,** and rangeland management.***

2. Synchronous, earth-orbiting satellites: ECON has recently performed economic analyses of the potential benefits of a variety of synchronous applications satellites including SEOS, SMS (GOES) and STORMSAT.† Benefits computed for these satellite systems derive from both earth resources monitoring and from weather observation in various areas of industry and agriculture.

3. Ocean monitoring satellites: Over the past year, ECON has performed and continues to perform studies†† relating to the potential benefits derivable from data obtained from a SEASAT

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*"The Value of Domestic Production Information in Consumption Rate Determination for Wheat, Soybeans, and Small Grains," ECON, Inc., Draft, August 1975.

**"A Parametric Study of the Value of Hydrological Information for Irrigation and Hydropower Management of the Feather River," ECON, Inc., Draft, August 1975.

***"The Value of Forage Measurement Information in Rangeland Management," ECON, Inc., Draft, August 1975.

†Some Economic Benefits of a Synchronous Earth Observatory Satellite," prepared by ERIM/ECON for NASA GSFC, September 1974.

"Supplement to Economic Benefits of a Synchronous Earth Observatory Satellite (STORMSAT Economic Benefits)," Prepared for ERIM by ECON, Inc., June 20, 1975.

"A Prospectus of Potential SEOS Economic Benefits," ECON, Inc., June 30, 1975.

††"SEASAT Economic Assessment," ECON, Inc., October 1974.

satellite system in ocean operations such as shipping, port and harbor management and extractive resource management.

Using these ECON studies as a basis, the benefit areas identified by the NAE Summer Study are discussed in the following sections (2.1 through 2.8). The areas of communications, materials processing in space and institutional arrangements for space applications which have not been studied previously by ECON are covered in subsequent sections. Table 2.1 represents in summary form the benefits discussed in this section. ECON benefits are classified as hard (adequately demonstrated by in-depth case studies) or soft (not derived from in-depth case studies); benefits in Table 2.1 represent "hard" estimates unless otherwise noted.

2.1 Weather and Climate

Benefits in this area have been estimated by ECON in the study of SMS, SEOS and STORMSAT, in terms of their estimated capabilities to improve weather forecasting. The benefits are the net cost savings that would result if the specified capabilities were achieved. User costs associated with the action/no-action decision were included. The studies found that improved weather forecasts could:

1. improve work scheduling in the construction industry;

Table 2.1 The Potential Economic Benefit of Remote Sensing Documented in ECON Studies

NAE Summer Study Benefit Area	Reference Document	Primary Economic Benefit Sources	Estimate of Potential Annual Economic Benefit in Primary Benefit Areas, $ millions
Weather & Climate	*	Cost reduction from improved weather forecasts	500-800 (360-600)+
Land Use Planning	Volume VI, Parts I and II***	Cost savings attributable to satellite over alternative data gathering systems	7.9-17.0
Agriculture	Volume III, Parts I, II &III****	Improved crop forecasts yielding better distribution and import-export decisions	247-549
Forest & Rangeland Management	Volume IV***	Improve timber harvest management, improve rangeland management, improve multiple use allocations	58.5 (30)++
Inland Water Management	Volume V***	Cost savings and increased value in power generation and agricultural water supply based on improved water run-off forecasts	50.6
Extractable Resources Management	Volume VII***	Cost savings due to improved ground feature detection	1.6-3.9
Marine & Maritime Applications	****	Efficiencies in ship routing and offshore oil production due to improved knowledge of clean conditions (weather, currents, etc.)	77-141
Environment	Volume V, VII, VIII & IX***	Improved detection of smoke and haze control of near-shore ocean pollution	1.5-3.3 (1.5-10.5)+++

+Benefits from STORMSAT are a subset of those from SEOS.
++Soft benefits obtained from studies performed outside of ECON.
+++Possible large benefits in air quality monitoring unquantified.

Sources: *"Some Economic Benefits of a Synchronous Earth Observatory Satellite," prepared by ERIM/ECON for NASA GSFC, September 1974.
**"Supplement to Economic Benefit of a Synchronous Earth Observatory Satellite (STORMSAT Economic Benefits)," prepared for ERIM by ECON, Inc., June 30, 1975.
***"The Economic Value of Remote Sensing of Earth Resources from Space: An ERTS Overview and the Value of Continuity of Service," ECON, Inc., December 1974.
****"SEASAT Economic Assessment," ECON, Inc., October 1974.

2. improve agricultural decisions such as planting, spraying, fertilizing and the use of smudge pots for frost protection;

3. allow for better power demand prediction by the power industries and permit more prompt power restoration during outages;

4. assist in planning urban and suburban highway snow removal by improving snowfall forecast accuracy.

These annual benefits have been estimated at $500 to 800 million for SEOS* and $360 to 600 million (a subset of the former) for STORMSAT.**

2.2 Land Use Planning

In ECON's study of benefits obtainable from an ERTS-like satellite, federal and state statutory requirements and expected requirements for land use data gathering were collected to form an aggregated statutory demand for land use data.*** These requirements were then categorized according to needed level of detail and those requirements which could be satis-

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*"Some Economic Benefits of a Synchronous Earth Observatory Satellite," prepared for ERIM/ECON for NASA GSFC, September 1974.

**"Supplement to Economic Benefits of a Synchronous Earth Observatory Satellite (STORMSAT Economic Benefits)," Prepared for ERIM by ECON, Inc., June 30, 1975.

***"The Economic Value of Remote Sensing of Earth Resources from Space: An ERTS Overview and the Value of Continuity of Service," Volume VI, December 1974.

fied by ERTS-1 type imagery were abstracted. Table 2.2 summarizes these projected requirements and the costs of their satisfaction. The conclusion of this analysis shows that the costs of an ERTS-like system can be covered (by comparative cost savings) merely by meeting projected land use information-gathering demand.

2.3 Agriculture

Substantial economic benefit has been shown to be obtainable from improved crop production forecasts using remotely sensed data.* Better crop forecasts reduce unwanted price fluctuations by facilitating the convergence of expected demand with expected supply whereas inaccuracies in crop forecasts cause inefficient inventory holding of crops. Potential benefits ranging from $247 to 549 million yearly are estimated for improved forecasts due to improved crop acreage measurement on the order of capability demonstrated by ERTS-1 Principal Investigators. Significant "soft" benefits have also been estimated to derive from improved crop production management and world-wide acreage and yield measurements.

2.4 Forest and Rangeland Management

Large areas in the U.S. offer valuable output in timber and forage and yet are imperfectly managed due to the dif-

*"The Economic Value of Remote Sensing of Earth Resources from Space: An ERTS Overview and the Value of Continuity of Service," Volume III, Parts I, II and III, December 1974.

Table 2.2 Discounted Total Program Cost (1977-1993) to Satisfy the Projected Future Nationwide Demand for Land Cover Information -- Level II Information -- Automatic Data Processing -- Allowable Cloud Cover (0-30%) (Millions of 1973 Dollars Discounted at 10% to 1974)

Projected Level II Demand	All Aircraft System	Lower Cost With Satellite Systems	Net Present Value	Equivalent Undiscounted Annual Cost Savings 1977-1993
1977-1993 Six times at 60 days	815.9 HA/GT	758.4 2S/HA/GT	57.5	7.9
1977-1984 Six times at 60 days 1985-1993 Eight times at 45 days	892.3 HA/GT	797.4 2S/HA/GT	94.9	13.0
1977-1980 Six times at 60 days 1981-1993 Eight times at 45 days	954.2 HA/GT	829.9 2S/HA/GT	124.30	17.0

Source: "The Economic Value of Remote Sensing of Earth Resources from Space: An ERTS Overview and the Value of Continuity of Service," Volume VI, December 1974.

Note: HA is High Altitude Aircraft
GT is Ground Truth Including Low Altitude Aircraft
S is Satellite
2S is Two Satellites

ficulty of obtaining comprehensive resource information. The sheer expanse of the areas in which timber is harvested and forage grazed makes information-gathering prohibitively costly. This current lack of information results in inefficient harvesting of available resources and, in the cases where over-utilization is very expensive, intentional under-harvesting. Remote sensing is a particularly applicable tool for information-gathering in these vast areas. Benefits in remote sensing of forest resources result from detection of over-utilized or under-utilized sections and the contribution toward the restoration of the order of maximum sustainable yield to these areas. This benefit has been estimated to be $28.5 million annually.

In rangeland mangement, inaccurate assessment of the forage resource leads to undergrazing or overgrazing, each of which involves an economic loss. Improved information permits better selection of cattle stocking rates and, thus, increased economic output. Estimates developed by the Earth Satellite Corporation* attribute an annual benefit of $30 million resulting from an ERTS-like system. However, this estimate was accepted by ECON only as a "soft" benefit estimate.

In an ongoing study,** ECON is investigating in more

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*"Earth Resources Survey Benefit-Cost Study, Rangeland Case Study." Earth Satellite Corp. and Booze-Allen Applied Research Corp., November 1974.

**"The Value of Forage Measurement Information in Rangeland Management," ECON, Inc., August 1975.

detail the effects of improved information in rangeland management. In particular, the effects of intentional undergrazing by ranchers in the face of uncertainty is examined; this intentional undergrazing results from the potentially high costs of overgrazing (and damaging a renewable resource) and the environment of uncertainty. Results from this study show that a very high capability system (in timeliness) is needed to be competitive with current rancher practices, but large benefits, on the order of $20 to 46 million, are possible from the use of current remote sensing systems in assisting on government-managed ranges.

Lands which find their use to be extensive (as opposed to intensive use, such as agriculture or industry) frequently can provide more than one service simultaneously. An example of multi-use is forests which produce timber but can also be used recreationally and as wildlife habitats. Improved information-gathering capabilities such as those possible via remote sensing allow resource inventories to be developed which permit better multi-use decisions to be made. The value of these improved inventories is estimated by ECON to be approximately $30 million.*

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*Op. Cit., "The Economic Value of Remote Sensing of Earth Resources from Space: An ERTS Overview and the Value of Continuity of Service," Volume IV.

2.5 Inland Water Management

Water impoundment areas are managed with the primary objective of avoiding floods. Secondary outputs of this management include electric power generation and agricultural water supply. Facilities which produce these latter economic outputs have limited throughput and, in cases where management feels that the level of water must be reduced, water is "spilled"; spilled water does not pass through facilities producing power or agricultural water and thus represents an economic loss. Economic benefit is obtainable from information which permits a decrease in spilled water or which allows the reservoir to be maintained at a higher level (a higher "head" produces more power per unit mass of water). This decreased spill and higher water level are possible from improved water runoff predictions (runoff representing input to the reservoir) because management can permit more water in the reservoir at no increased risk of flooding. Remote sensing systems can provide measurements of snow pack within a water basin which aid in predicting the quantity of water runoff.

Early estimates placed the yearly value of improved runoff forecasts resulting from a LANDSAT-like system at about $50.6 million.* A more recent study, however, has shown that in the Oroville Reservoir of the Feather River water district, 92%

*Ibid, Volume V.

of the runoff forecast error was due to the inability to predict weather, leaving little room for benefits from snow pack measurement.* A current ECON study as a part of the TERRSE project for NASA is examining the relationship of snow pack to runoff forecasts in other river basins to determine what benefits in this area could be obtained at a national level.

2.6 Extractive Resources Management

In a volume entitled "Nonreplenishable Natural Recourses: Minerals, Fossil Fuels and Geothermal Energy Sources,"** ECON investigated the potential application of remote sensing to resource extraction. The findings of this study conclude that the ability of remote sensing to assist in the location of mineral deposits has not been adequately demonstrated. Although a significant cost savings was shown by a Principal Investigator in "locating promising exploration sites," the ability to generalize to different geological areas has not been shown. Cost savings to private and government institutions in geologic mapping contributes $1.6 to $3.9 million to annual benefits obtainable from remote sensing.

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*"A Parametric Study of the Value of Hydrological Information for Irrigation and Hydropower Management of the Feather River," ECON, Inc., Draft, August 1975.

**"The Economic Value of Remote Sensing of Earth Resources from Space: An ERTS Overview and the Value of Continuity of Service," Volume VII, ECON, Inc., December 1974.

2.7 Marine and Maritime Applications

As regards space-based systems for marine and maritime applications and the potential benefits therefrom, ECON has performed a preliminary benefit assessment* of a global ocean monitoring satellite, SEASAT. The study focused on six selected user applications of SEASAT; benefit estimates were completed for each user application through case study analysis and these were then generalized (to national or world-wide benefits) for each application. The generalized potential economic benefits for the user applications are shown in Table 2.3. Note that the benefits cited are the total benefits discounted at 10% over the planning horizon from 1974 to the year 2000. The equivalent potential annualized benefits to the U.S. over the same time period (again using a 10% discount rate)

Table 2.3 Present Value (1974 $) of Partial Aggregate Benefits (Millions of Dollars)

Benefit Source	Benefit Lower Bound 10% Discount Rate	Benefit Upper Bound 10% Discount Rate
Optimum Ship Routing (U.S. Trade)	110	110
Iceberg Reconnaissance	11	36
Canadian Arctic Operations	270	435
Sea-Leg of Trans-Alaska Pipeline	13	13
Off-Shore Oil Production	264	660
Military Applications	28	28
TOTAL	696	1282

*SEASAT Economic Assessment, ECON, Inc., October 1974.

are $77 million and $141 million as lower and upper bounds respectively. The phrase "partial aggregate benefits" in Table 2.3 is used to emphasize the fact that only a selected sample of user applications of SEASAT are being reported on.

2.8 Environmental Management

ECON has found various possible applications of remote sensing in environmental management. The ability of an orbiting satellite to sense large areas in short periods of time make early detection of pollution possible, so long as the event is not too short-lived. Additional study of the forces which disperse point source pollution could lead to the understanding of techniques that permit optimal or planned release of pollutants.

The State of New Jersey found this application valuable in siting ocean outfalls; they placed the value of LANDSAT-1 images contribution at $0.62 million. The ability of LANDSAT data to assist in shoreline protection programs and to detect offshore oil spills is valued at an additional one million dollars annually.* Should remote sensing demonstrate an ability to monitor air pollution, additional annual benefits of $1.5-10.5 million would be obtainable.**

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*"The Economic Value of Remote Sensing of Earth Resources from Space: An ERTS Overview and the Value of Continuity of Service," ECON, Inc., Volume IX, December 1974.

**Ibid, Volume VIII.

3.0 A SURVEY OF THE ECONOMICS OF MATERIALS PROCESSING IN SPACE

3.1 Background

3.1.1 The Historical Development of Materials Processing in Space

During the late 1960s several researchers in NASA began studies of the use of the space environment to perform studies of the use of the space environment to perform materials processing operations that are not technically feasible or not economically attractive on earth. To a great extent, these studies were an outgrowth of the consideration of the problems of using welding techniques for assembling large objects in orbit from parts that had been prefabricated on earth. The studies showed that the physical characteristics of the space environment, namely virtual weightlessness, a vacuum sink of unlimited capacity, and the availability of solar energy, are potentially useful in materials processing. Of these, weightlessness is the most important as it cannot be duplicated on or near earth for more than a few seconds.

During the mid-1970s the interest in materials processing in space progressed from studies and ground-based experimentation and technology development through a series of simple experiments in the Apollo 14, 16, and 17 missions. The Apollo experiments consisted of weightless solidification experiments and small scale electrophoresis tests.* The Apollo experiments were relatively encouraging and showed that worthwhile results could be obtained in space processing using relatively simple and inexpensive experiments.**

As a result of the success obtained in the Apollo flights, a more extensive series of materials processing experiments was planned and implemented in the Skylab program. Figure 3.1 is a tabulation of the Skylab space processing experiments and science demonstrations. In addition to the fifteen formally scheduled experiments, a group of minor ad hoc experiments called science demonstrations were added to the Skylab III and IV missions. These science demonstrations made use of hardware and materials available aboard the spacecraft. Although one (M555) of the fifteen scheduled experiments could not be performed as its stowage space was preempted by the Skylab Repair Kit, a high level of crew productivity was obtained during the Skylab mission and several of the space processing experiments were run twice. In general, the Skylab experiments dealt with melting and freezing processes and the behavior of fluids. Although the discussion of the specific results of the Skylab experiments is beyond the scope of this

*Final Report of the Space Shuttle Payload Planning Working Groups. Materials Processing and Space Manufacturing, NASA Goddard Space Flight Center, May 1973.

**Extract from the Space Applications Program, 1974. Overview of NASA Application Program prepared for the 1974 NASA/NAE Applications Summer Study, May 1974.

	Skylab Mission II	III	IV
Material Processing Facility			
M551: Metals Melting Experiment, Mr. R.M. Poorman, MSFC Astronautics Lab	X		
M552: Exothermic Brazing Experiment, Mr. J.R. Williams, MSFC Product Eng. Lab.	X		
M553: Sphere Forming Experiment, Mr. E.A. Hasemayer, MSFC Product Eng. Lab	X		
*M555: Gallium Arsenide Crystal Growth Experiment, Dr. R.E. Seidensticker, Westinghouse Res. Lab			
Multipurpose Furnace System			
M556: Vapor Growth of II-VI Compounds, Prof. H. Wiedemeier, Rensselaer Poly. Inst.		X	X
M557: Immiscible Alloy Compositions, Mr. J.L. Reger, TRW Systems		X	X
M558: Radioactive Tracer Diffusion, Dr. A.O. Ukanwa, MSFC Space Sciences Lab		X	
M559: Microsegration Germanium, Dr. F.A. Padovani, Texas Instruments		X	
M560: Growth of Spherical Crystals, Dr. H.U. Walter, University of Alabama		X	X
M561: Whisker-Reinforced Composites, Dr. T. Kawada, Nat. Inst. for Metals Res., Japan		X	X
M562: Indium Antimonide Crystals, Prof. H.C. Gatos, Mass. Inst. of Tech.		X	X
M563: Mixed III-V Crystal Growth, Prof. W.R. Wilcox, Univ. of Southern Calif.		X	X
M564: Alkali Halide Eutectics, Prof. A.S. Yue, Univ. of Calif., Los Angeles		X	
M565: Silver Grids Melted in Space, Prof. A. Deruytherre, Katholieke Univ., Leuven, Belgium		X	
M566: Copper-Aluminum Eutectic, Mr. E.A. Hasemeyer, MSFC Product Eng. Lab		X	X
Science Demonstrations			
Diffusion in Liquids		X	
Ice Melting		X	
TV 101 Liquid Floating Zone			X
TV 102 Immiscible Liquids			X
TV 103 Liquid Films			X
TV 105 Rochelle Salt Growth			X
TV 106 Deposition of Silver Crystals			X
TV 107 Fluid Mechanics Series			X
TV 117 Charged Particle Mobility			X
Experiments Performed on Each Mission	3	13	14

*Not flown-storage area preempted by Skylab Repair Kit.

Figure 3.1 Skylab Experiments and Science Demonstration

Source: NASA ES75-15310 [1], 12-4-74.

report, the results indicate the possibility of producing higher quality crystal materials in the space environment than can be produced by comparable processes at present on earth. Specifically, Experiment M560 supported the possibility of making high quality crystals directly in wafer form in space, thus avoiding the wastage and degradation of material caused by the cutting, grinding and polishing processes used to produce such wafers on the ground. Moreover, Experiment 562 yielded crystal material with more uniform electrical properties than that achieved with comparable samples grown on earth.*

The next step in experimentation in materials processing in space will occur in the Apollo-Soyuz Test Project (ASTP) planned for 1975. Figure 3.2 is a tabulation of the ASTP experiment program. The series of experiments involving the Multipurpose Furnace System (MA-010), and the crystal Growth in Space experiment (MA-028), essentially involve the continuation of the research with inorganic materials begun during the Skylab program. The other two ASTP experiments (MA-014 and MA-011) are concerned with a different area of space processing: the separation of biological materials to isolate specific materials that are important for medical

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*Testimony to Congress by Special Programs, NASA Headquarters, 1975.

ELECTROPHORESIS EXPERIMENTS

MA-014: ELECTROPHORESIS - EPE
Dr. K. Hannig, Max Planck Inst.

MA-011: ELECTROPHORESIS TECHNOLOGY
Dr. R. S. Snyder, MSFC Astronautics Lab.
Dr. P.E. Bigazzi, State U. of New York
Mr. G. A. Barlow, Abbott Laboratories
Dr. M. Bier, Veterans Administration

MA-010 MULTIPURPOSE FURNACE SYSTEM

MA-041: SURFACE TENSION INDUCED CONVECTION
Dr. R. E. Reed, Oak Ridge Nat'l. Lab.

MA-044: MONOTECTIC AND SYNTECTIC ALLOYS
Dr. C. Y. Ang, Northrop Corp.

MA-060: INTERFACE MARKING IN CRYSTALS
Prof. H. C. Gatos, MIT

MA-070: ZERO-G PROCESSING OF MAGNETS
Dr. D. J. Larson, Grumman Corp.

MA-085: CRYSTAL GROWTH FROM THE VAPOR PHASE
Prof. H. Wiedemeier, Rensselaer Poly. Inst.

MA-131: SODIUM CHLORIDE - LITHIUM FLUORIDE EUTECTIC
Prof. A. S. Yue, UCLA

MA-150 MULTIPLE MATERIAL MELTING
USSR

COOPERATIVE EXPERIMENT

MA-028: CRYSTAL GROWTH IN PLACE
Dr. M. D. Lind, Rockwell International

Figure 3.2 ASTP Experiments

Source: NASA Headquarters ES75-15563(1), January 16, 1975.

research and applications. Both of these experiments will employ an electrical separation technique known as electrophoresis to separate certain classes of human cells into groups that have different functions or properties. The weightlessness and quiet nature of the space environment are both important to the electrophoresis process. On earth, electrophoresis and related techniques are successful only in arrangements where the separation medium is stabilized against convection and other mechanical disturbances either by containment in a porous supporting medium or by a stable flow regime. The electrophoresis experiments are of major importance to the biomedical community and could possibly contribute to the development of new approaches to the treatment of disease and the stabilization of transplanted organs.

3.1.2 The Relationship of the Space Shuttle and Spacelab to Materials Processing

The advent of the Space Shuttle and Spacelab in the 1980s will provide new opportunities for experimentation in the processing of materials in space. By its very nature, materials processing tends to involve repetitive use of the processing equipment. The Space Shuttle/Spacelab will combine the attractive features of the space environment with the capability for frequent, repetitive reuse of the processing equipment.* Using the Space Shuttle, an extensive program

*Study for Identification of Beneficial Uses of Space (Phase I), Contract NAS8-28179, Final Report, Volume I, December 10, 1972.

of applied research could result in demonstrations of technical feasibility that subsequently could lead to the development of operational or commercial processing of materials in space. Preliminary planning for the selection of space processing experiments for the Space Shuttle has been going on since 1972. In the interim between the flight of ASTP in 1975 and the Space Shuttle/Spacelab in the 1980s, research and development in space processing of materials will continue with an active program of ground-based investigation and a series of suborbital rocket flights.

3.1.3 The Objectives of Economic Analysis

The purpose of this section is to identify what areas of materials processing in space give preliminary indication of economic benefits, and to identify possible ways to estimate the size of the benefits. Since the field of materials processing in space is in the formative experimental stage, it is premature to attempt to justify operational or commercial processing on the basis of the results obtained to date. However, at this time, economic analysis can be used as a management tool to identify potential benefit areas and guide research and development toward those areas of large potential economic payoff, as well as serving as a framework for developing the nature of prospective uses and users for materials processed in space. For example, alternative space materials processing research and development projects can be considered as alternative investment opportunities, and assessed from the viewpoint of net payoff on each of the projects. Using payoff as a guideline for project selection, projects with a high payoff should be undertaken while those with a low payoff should not. For comparability between projects, payoff can be expressed as the net present value of benefits less the net present value of costs at a specified discount rate. With discount rate as a parameter, a project with an expected positive net present value at 15% discount rate is one that almost certainly should be undertaken. The lower the value of the discount rate at which the net present value of the benefits equals the net present value of the costs, the less the economic motivation to undertake the project.

Research and development in space materials processing may be considered to contain a relatively high degree of risk in terms of eventual economic payoff. Some economists believe that the government does not need to behave in the same way as the private sector with respect to risk. Since the government undertakes many research and development projects with varying degrees of risk, it has the option of pooling risks in much the same manner as an insurance company and does not need to apply a differential risk penalty on its own projects. Thus, the government can undertake research and development projects that would be rejected by industry as being too speculative.

3.2 The Nature of Materials Processing in Space

There is a natural division between the applications of space processing to conventional materials technology and the biomedical applications. The biomedical applications involve organic materials, while the applications to conventional materials technology are concerned with inorganic materials.

The following paragraphs describe some of the potential products of space processing with emphasis on the potential uses and users of the products. Where possible, potential economic implications of the products are described, along with an approach that could be used to estimate the potential benefits. All of the applications described are speculative, some more so than others. In some cases the applications can be focused to a specific end objective and an available data base exists to make possible a benefit model and an estimate of the benefits. Other applications are of a much broader research nature and this represents a more difficult (but not impossible) data collection and modeling problem. For this reason, this review concentrates on these applications where the benefit model and data base are readily identifiable.

The ability to quantify benefits at this time should not be construed as a measure of the worth of an application, but as a suggestion of the fact that the application is sufficiently focused to enable the identification of the uses, users and the potential relationship between the technology and economic benefits. While the path to success may be more tenuous in some of the applications where no recommendation is made to estimate benefits at the present time, the implications of success in these areas may be as far-reaching (from an economic viewpoint) as those areas that are presently quantifiable.

3.2.1 Inorganic Materials

3.2.1.1 Electronic and Electro-Optic Devices

The previously described and referenced Skylab space processing experiments demonstrated the possibility of producing crystals of higher quality, larger size and more uniform electrical properties than can be produced at the present time on earth. The most likely candidates for processing in space will probably be the semi-conductor and ceramic oxide crystals for electronic and electro-optical devices. Examples include silicon, gallium arsenide and bismuth germanate. Other electronic devices such as rare earth iron garnet crystals for use in magnetic bubble memories also appear to be candidates for space processing. Studies performed in 1972 supported the technical and economic feasibility of space processing of sophisticated compound single crystals and magnetic bubble memories.* However, the rapid innovation and advance of technology in electronic and electro-optic devices may introduce new or improved devices involving new technologies that could supersede these crystal applications by the mid 1980s. Thus, if economic benefits are realized through the production of electronic or electro-optic devices using materials processed in space, it is likely that the devices will not be simple improvements of devices that can now be made on earth, but may be new compositions that result from experimentation with materials in the space environment. However, it should be borne in mind that the experiments with space-grown crystals performed to date compare materials processed exactly the same way in space and on the ground, the only difference being the presence or absence of gravity. While this approach may be scientifically valid for isolating the effect of gravity, the practical significance of space processing will be apparent when space grown crystals are compared with the best crystals grown on earth by any economically or technically viable method. This is particularly so, as, according to some scientists, the results observed in space grown crystals could have been produced on earth if

*Economic Analysis of Crystal Growth in Space, Final Report, Contract NAS8-27842, July 1972.

different, experimental techniques had been used.* On the other hand, further experimentation in space may show that the absence of gravity does not produce spontaneous improvements in processes that also work satisfactorily on the surface of the earth. Rather, it may be that the absence of gravity allows manipulations or process conditions that affect the properties of the materials, but will not work or cannot be controlled on the ground.

Since it is unlikely that space processing will be used for devices that are currently in production or development, it will be necessary to perform a technical forecast before the benefits of space processing can be estimated. A method of technical forecasting that could be used would be to draw upon the technical expertise of the Skylab and ASTP investigators in this area to describe the expected technology benefits or applications of their experiments. Using this information, industrial researchers could then be surveyed to determine usefulness of the expected results to specific research applications. A speculative estimate could then be made of possible product developments and demand and cost estimates made for the products. While this approach appears to be straightforward, the results could be limiced by the

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*Crystal Growing in Space: Significance Still Up in the Air, Science, Volume 187, February 1975.

highly competitive nature of the industry and the fact that the forecast will deal with products that have not yet been "invented."

3.2.1.2 High Temperature, High Strength Structural Materials

It has long been known that directional solidification of alloy systems can produce improvements in the mechanical properties of the material. Since 1958 studies have been performed on eutectic and near-eutectic melts of metals, oxides, and salts because of the unique microstructures that can be developed in these systems. These mixed phase composite materials have potential application in fields such as high temperature metallurgy, toughened ceramics, and super conducting systems. In the processing of eutectic materials, the weightless space environment appears to suppress the random effects of convection, so that the heat and mass transport effects that govern solidification become highly predictable, yielding a convectionless directional solidification process.* A benefit/cost study of the use of space processed eutectic material in aircraft gas turbine blades performed during 1974 indicated that there would be an adequate demand to justify production of space processed blades both from a quantity and benefits derived standpoint. The

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*Space Processing -- Status, Prospects, and Problems -- 1974, Steg and McCreight, General Electric Company, Space Sciences Laboratory, September 1974.

study was based upon the technical assumptions that the space processed materials would yield an added 200°F temperature tolerance, reducing fuel consumption by 4% and doubling blade life for existing aircraft with respect to blades processed on earth. The results of the study indicate a cost savings of $4.744 billion (0% discount rate) for the 1980-91 time period, as opposed to a production cost (including an allocation of Space Shuttle operating costs) or $1.246 billion (0% discount rate). A review of this study by one of the leading producers of jet turbine blades raised questions concerning the technical and market assumptions and, hence, the validity of the economic benefits. The review indicated that the use of eutectic alloy blades is presently limited by the absence of reliable high temperature coating materials which limits the possible increase in blade operating temperature to approximately 50°F. Moreover, based upon current marketing experience, it appears that aircraft gas turbine manufacturers are not willing to pay the increased price for eutectic alloy blades, even though eutectic alloy blades (now produced on earth) exhibit life extension capabilities of four (4) to seven (7) times that of a conventional blade.* The reluctance to incorporate eutectic alloy blades may be due to the fact

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*Personal Correspondence, R. L. Harnel, Materials Technology Department, TRW Systems Group, February 1975.

that the life of present blades is long when compared to the time between teardown of jet engines. Thus, it would appear at present that the need is not for increased performance or life, but perhaps for reduced initial cost, or for a corresponding improvement in the life of other jet engine components in order to make their life expectancies approximately equal to that of the eutectic blades.

3.2.2 Biological Materials

3.2.2.1 Processing Considerations

The primary direction of research in space processing of organic materials has been in the area of electrophoretic separation and purification of biological materials. Electrophoretic separation processes are based upon electrochemical effects that cause particles to take on electrical charges when suspended in aqueous solution. The nature of these charges is determined by the equilibrium between particle surfaces and ions in the solution, so that the charges are characteristic of the particles, but can also be manipulated to some extent by changing the composition of the solution. Forces can be applied to the charged particles by applying an electrical field to the solution. When this is done each particle will move along the direction of the field at a constant velocity such that the fluid drag forces are equal and opposite to the electric force on the particle. Thus, in general, each kind of particle suspended in a solution in this manner moves when an electric field is applied with a characteristic velocity determined partly by its chemical nature, and partly by its size and shape. Using this principle of electrophoretic separation, particles that move at different velocities can be physically separated and separately collected.

The use of electrophoretic separation techniques on earth is limited by the effects of gravity. In space, the absence of a significant gravity field increases the suspension time of heavy particles in the solution, and suppresses convective effects. On earth, gels, paper, starches and small dimensions are all used to minimize convection and sedimentation effects on the electrophoretic process. Since the heavy particles of interest include living human and animal cells, the increased dwelltime of these heavy cells in the space environment is of major importance. Estimates indicate that it should be possible to increase the size of cell separated from approximately 1mm to approximately 6mm in space.

Freeze drying of biological materials may also be improved by the space environment. Freeze drying is often used as a means of preserving prepared biological material. The weightless environment may improve freeze drying by permitting evaporation of ice from all surfaces of a particle at the same time.

3.2.2.2 Material Types and Potential Applications

Two types of biological materials, namely molecular and cellular, have been considered for processing in space. The common technique for the processing of both types of materials is electrophoresis. The areas discussed below are areas in which there currently is a high level of research activity, and these are probably areas in which additional progress will be made during the five year interval between the ASTP and early shuttle flights. As such, these are probably not the exact products that will be of interest in the 1980s, but are concrete examples of present needs for processes or products that could conceivably be improved by materials processing in the space environment.

3.2.2.2.1 Cellular Material

The following paragraphs describe two potential applications of space-based processing of cellular material that could have significant economic impact. It should be noted that other potential applications based upon the electrophoretic mobility of cells and their functional properties such as the separation of functionally defined lymphoid cells have been considered and may also be of major importance.

3.2.2.2.1.1 Human Lymphocytic Group Separation

Human lymphocytes are a class of white blood cells that control much of the human body's immune responses to disease and organ transplant rejection. For example, current kidney transplantation research is exploring the use of various lymphocyte culture response tests to enhance selection criteria for donor-recipient pairing. In the case of living related donor-recipients, a Mixed Leukocyte Culture (MLC) Response Test has been developed to yield an indirect measurement of the recipients immunological response to his donor. While limited primarily to parental and sibling donors, the MLC test has been successfully used to reject several potential donors who might, by prior criteria alone, be given a kidney with less than acceptable odds for survival. A modified version of the MLC test is also under development in an effort to detect cell-mediated immunization and produce a more biologically refined classification of cadaver transplant recipients. While mortality as a result of a kidney transplantation has been reduced to approximately 10% during the past ten years, the problem of ultimate rejection of the transplanted organ remains an important consideration. Studies by the Rogosin Kidney Center indicate a one year predicted kidney survival of 44% for cadaveric transplants (for the period 1963-73), but indicate that this could be improved to greater than 80% by proper selection of cadaver graft recipients. While research tests for matching the donor and recipient have been developed that might lead to an 80% predicted survival for one year, these tests are not generally applicable in every day practice. The use of these research tests in every day practice would effectively reduce the number of transplants and increase the average time spent in dialysis by the potential recipient. Thus, in many cases at the present time a transplant is effected even though the probability of predicted survival for one year (based upon matching experience and survival statistics) may be much less than 80%.

To date, two major classes of human lymphocytes have been identified. It has been hypothesized that there are several subgroups within these major groups, and that these subgroups play an important role in enhancing or suppressing the immunological reaction to the transplanted kidney. One of the hoped for results in the electrophoresis experimentation with cellular material in space is the identification of the lymphocyte subgroups. If this is successful, the donor/recipient matching process could be improved and, perhaps more importantly, the factors that cause rejections could be specifically identified. If the latter is achieved, it may be possible to devise a serum to suppress or neutralize the rejection process without destroying the remainder of the patient's immune systems. Thus, if successful, space materials processing experiments aimed at separating the lymphocyte subgroups could make possible a dramatic improvement in the survival of transplanted organs.

A review of the current literature indicates that an economic assessment of the potential benefits of improved human lymphocyte subgroup classification has not been performed. Two categories of economic benefits are associated with the survival of the transplanted kidney. The first category is the economic value of the human lives involved, while the second is the reduction of the costs of the federally supported dialysis program. The value of the lives can be estimated by determining the average age of death as a result of kidney disease, the average expected income of the kidney transplant recipients, and the expected increase in life span as a result of the improved survival kidney transplants. Since 1972 the costs of dialysis have been paid for under the Social Security Act for those patients who have had a transplant or who receive dialysis more than once per week. While estimates of the costs of dialysis range widely, it has been estimated that the annual cost for hospital-performed dialysis is in the range of $15,000 to $47,000 per patient/year. It has further been estimated that out of the population of about 58,000 people in the U. S. with serious and significant kidney disease, approximately 10,000 are medically and psychologically equipped to handle long-term dialysis. Using these figures, it can be seen that the direct cost of the federally supported dialysis program could reach $150 million to $470 million per year in the near term and, as medical techniques are improved and a larger part of the potential population is accepted for dialysis, the cost could increase to nearly $1 billion per year. It should be noted that these figures represent direct costs of the dialysis program and do not include estimates of lost income and production effects. Discussion with Dr. Albert Rubin of Cornell University Medical College indicates that the mechanism for achieving economic benefits as a result of human lymphocyte subgroup separation would be the improved survival rate of the transplanted organs through better matching of the donor and recipient, and suppression of the rejection process. The latter could also result in an increase in the number of potential transplant candidates. Both of these factors could cause a reduction in the number of patients on dialysis. The data base for assessing the economic potential of this area exists as a result of the federally supported dialysis program. Data such as the incidence of kidney disease, the availability of transplants, the survival rates of the transplanted kidney and the costs of the dialysis program are available from various federal and private sources. Since the technical feasibility of human lymphocyte subgroup separation has not yet been demonstrated, it is suggested that a probabilistic approach be used for the benefit assessment in order to indicate the range of uncertainty associated with the results.

It should be noted that other organ transplant operations where rejection of the transplanted organ is an important factor could also possibly benefit from successful human lymphocyte subgroup separation. In comparison to the eva uation of the economic benefits of improved kidney transplantation, the economic benefits of the more generalized problem of improved organ transplantations have not been examined in this study. The more generalized benefits may be more difficult to assess as a result of the lack of a comparable data base; however, hospital and insurance company records could possibly provide useful data. It is suggested that the generalized problem be explored in a detailed study of this subject.

3.2.2.2.1.2 Urokinase Research and Production

Urokinase is an enzyme, produced by human kidney cells, which has been found to be effective in removing blood clots from veins and arteries when administered in large doses.* Abbot Laboratories is attempting to develop processes

*Testimony to Congress. Special Programs, NASA Headquarters, 1975.

to produce urokinase on a large enough scale for routine medical use, and have proposed a kidney cell separation experiment (MA-011) for the ASTP mission. Mr. Grant H. Barlow of Abbott Laboratories indicates that urokinase has been tried clinically for the prevention of pulminary embolism following surgery, and has been found to be medically effective. The original supply of urokinase was produced from human urine at a cost per dose of approximately $1500. Thus, the high cost and low availability of urokinase precludes its general use at the present time. Current efforts aimed at the production of urokinase in economically useful quantities are based upon the fact that human kidney cells grown in a culture produce the enzyme urokinase. Growth of the cells in a culture on earth is limited by the available surface and, in the absence of gravity, it may be possible to increase the surface in contact with the nutrient. The production of urokinase is further limited by the fact that only approximately 5% of the cells in the culture produce the enzyme. Various investigators, including Mr. Barlow, have hypothesized on the basis of ground tests using electrophoresis in a magnetic field that it may be possible to isolate the urokinase-producing cells in a space-based electrophoresis process. If the urokinase-producing cells can be isolated it should then be possible to greatly increase the ratio of urokinase-producing cells to non-producing cells in a culture. Thus, with a given quantity of kidney material, and a fixed time that might be established by limitations of the nutrient or the inability to remove toxic products from the culture, it should be possible to obtain a higher yield of urokinase from a concentrated mix of producing cells. This could conceivably lead to the capability to produce large quantities of urokinase at a reduced price.

A review of the available literature indicates that the economic aspects of the prospective capability to produce large quantities of urokinase at a reduced price have not been explored. In a manner similar to the recommended kidney transplant and dialysis study (3.2.2.1.1), the data base needed to support a study of the economic impact of space-based materials processing on the production of urokinase should be available from various government and private sources. The incidence of death and disability induced by blood clots can be obtained from medical statistics, and the potential impact of urokinase can be estimated from the results of clinical studies. The demand for the product and its potential utilization can also be related to the price per dose. Since the ASTP experiment may produce rather specific insights into the feasibility of separating the urokinase-producing cells from other human kidney cells, this area could rapidly assume increasing importance in the planning of Space Shuttle-based space materials processing experiments. Consequently, it is recommended that a preliminary economic study of the prospective benefits of using space-based facilities for the separation (and possibly growth) of urokinase-producing kidney cells should be conducted.

3.2.2.2.2 Molecular Material*

Several molecular biological products, all with the common base of the potential use of electrophoresis for purification, have been considered as typical candidates for space materials processing. Although the spectrum of potential medical applications of these materials could be extremely broad, some experts believe that space-based electrophoresis may not play as decisive a role in the separation of molecular species as in the separation of cellular species. Some of these molecular products and potential applications are described in the following sections.

3.2.2.2.2.1 Erythropoietin

Erythropoietin is a hormone capable of increasing the total number and volume of circulating red blood cells in a normal animal. Its potential value lies in the treatment of renal failure or anemia, and the ability to avoid complications of the present form of treatment involving repeated transfusions of whole blood or red cells. Relatively

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*Space Processing -- Status, Prospects, and Problems -- 1974, Steg and McCreight, General Electric Company, Space Sciences Laboratory, September 1974.

high purity erythropoietin is required for the treatment of humans, but has not yet been obtained in sufficient quantity for clinical testing. There is some expectation that space-based electrophoresis may prove to be a practical separation and purification method. No estimates have been made of the demand for clinically effective erythropoietin; however, it may be possible to estimate the economic impact of the development of clinically effective erythropoietin by examining the incidence of anemia and the cost of present treatment using transfusions of whole blood or red blood cells.

3.2.2.2.2.2 Other Research Applications

Several other research applications for space-based electrophoresis have been suggested, including the production of highly purified quantities of Factor VIII (antihemophilia Factor), purification of subunit viral vaccines, separation of antibodies for cancer research, and the identification of subclasses of lippoproteins for use in the study of arteriosclerosis. All of these potential applications of electrophoresis in a gravity free environment are primarily of a more speculative research nature than the other organic materials applications discussed in this review. Several of these research applications could possibly lead to major breakthroughs in the field of medical science with attendant large potential economic impact. However, in each case the technology is highly speculative, and considerable further research and development should be performed before specific economic implications can be considered.

3.3 Conclusions and Recommendations

An ultimate objective of the space materials processing programs is to bring the technology to the point where industry will want to participate on a commercial basis. The demonstrations of technical feasibility of materials processing in space needed to obtain commercial participation in the program have not yet occurred, although the results obtained to date have been sufficiently encouraging and interesting to merit further experimentation. In the absence of demonstrated feasibility, it is premature to attempt to justify operational space materials processing on the basis of the results of experimentation to date. However, the results to date have been encouraging and supportive of the conduct of further experimentation. Given the constraint of a limited budget, and the opportunity for many experiments, economic analysis can be used as a management tool in the ranking and selection of experiments. In this context, economic analysis can be used to identify areas of large potential benefits, and to serve as a framework for developing the nature of prospective uses and users for materials processed in space.

Limited economic studies have been performed to date, primarily in the area of space processing of inorganic materials. While these studies indicate the prospect of economic benefits in the area of electronic and electro-optic devices, the technology in this area has competitively and rapidly advanced in the past years, and the devices considered desirable today may be superseded by the time that the Space Shuttle is available to support further large scale experimentation. Further economic studies in this area should concentrate in a speculative fashion on the potential impact of space processing of inorganic materials, based upon technology forecasts into the mid-1980s.

The economics of space processing of cellular and molecular materials for biological and medical purposes has not received adequate attention and should be the subject of further study. An examination of the economics of this area could help focus research objectives, and provide impetus to a broader program. While the success of specific processes remains to be demonstrated, the economic impact of a successful space research program can be demonstrated in at least two applications. Specifically, it is recommended that economic studies be performed on the potential of the impact of human lymphocyte subgroup separation on organ transplantations and on the separation and concentration of urokinase-producing cells leading to the capability to produce large quantities of urokinase at a reduced price. In both of these areas the data base exists to support a substantive, quantitative economic assessment of the impact of a successful research and development program.

4.0 A SURVEY OF THE ECONOMICS OF WEATHER FORECASTING

ECON's analysis of the potential economic benefits from improved weather forecasting began with an extensive literature search and review. A bibliography of the relevant documents examined is given in Appendix A to this report. Of these documents, comprehensive and quantitative studies have been completed by J.C. Thompson*, and by ECON** in the evaluation of potential benefits attributable to various satellite systems.

4.1 Overview of the Potential Economic Benefits from Improved Weather Forecasting

Thompson's approach is to develop a "meteorological-economic" model which relates potential improvements in meteorological information to the associated economic benefits that accrue from the prevention of weather related losses through timely protective actions made possible by improved weather forecasting. The model was developed from actual historical records of weather forecasts and measures of the reliability of present day forecasts and actual accounting records detailing the monetary value of weather related losses in various agricultural, commercial and industrial organiza-

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*Thompson, J.C., The Potential Economic Benefits of Improvements in Weather Forecasting, California State University, San Jose, California, 1972.

**Bhattacharayya, R., et. al., A Benefit Assessment of Stormsat, Final Report, ECON, Inc., Princeton, New Jersey, June 30, 1975.

tions. The model examines not only the total economic losses due to adverse weather but also the amount of such losses which are preventable through timely protective action. The latter category (protectable losses) is further subdivided according to whether the necessary protective actions are due to improved utilization of information available from current scientific knowledge or whether the preventable losses require an increased scientific understanding of weather processes. Potential economic gains of the former type are classified as operational improvements while the latter type gains are classified as scientific advances. The potential economic gains defined by this model were computed from forecasts provided by the U.S. National Weather Service.

The total protectable losses to the U.S. economy were estimated by Thompson at $5.3 billion annually. His analysis suggests that about 14% of these protectable losses or $739 million annually can be saved by improved weather forecasts. (Even with perfect forecasts, information dissemination and decision making, the cost of protective action will prohibit full recovery of the protectable losses.) As considered by Thompson, further cost savings could only be achieved through modification and control of the weather and climate.

Figure 4.1 illustrates the total and protectable losses over all application areas investigated in the

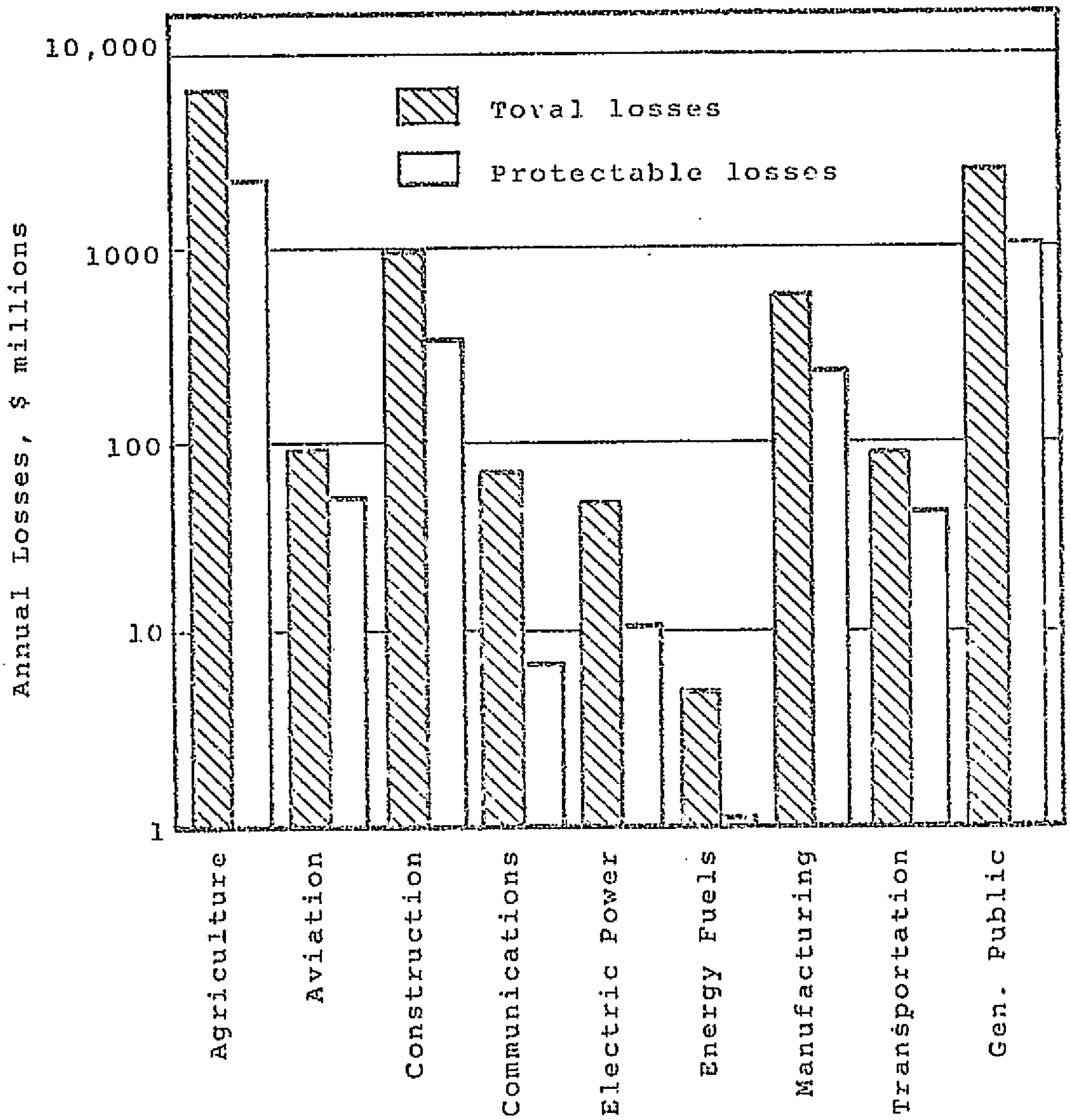

Figure 4.1 Annual Monetary Losses due to Adverse Weather in the United States. (After J.C. Thompson)

Thompson study. It is clear from this diagram that the four major areas of protectable losses are agriculture, construction, manufacturing and general public activities (including government service activities). Care must be exercised in interpreting this report since the vertical scale (annual losses/gains) is logarithmic. Accordingly, Thompson concludes that agriculture is by far the largest potential benefit area.

Table 4.1 gives a clearer picture of the relative economic potential of improved weather forecasting by application area. These total gains, representing an estimate by Thompson of benefits less the costs of achieving the benefits, comprise approximately 14% of the protectable losses. In addition, an analysis of the total potential gain in terms of operational improvements or scientific advances is provided. While the latter source of economic benefits uniformly dominates the former, both sources of benefits are substantial.

The potential economic benefits estimated by Thompson that may accrue to various user groups from improved weather forecasting are highly dependent on the weather forecast warning period. Table 4.2 shows the user group minimum required warning time in order to take protective action against adverse weather to achieve the maximum realizable potential benefits (preventable losses). Though not suprising, it is of interest to note that the agricultural uses of weather information are most sensitive to the length of the forecast

Table 4.1 Summary of Potential Annual Savings due to Improvements in Weather Forecasting in the United States.*

	Potential Annual Savings, $ millions		
	Operational Improvements	Scientific Advances	Total Gains**
Agriculture	250.3	316.7	567.0
Aviation (commercial)	1.4	2.2	3.6
Construction	13.1	18.4	31.5
Communications	0.3	0.4	0.6
Electric Power	0.5	0.8	1.3
Energy (e.g., fossil) Fuels	#	0.1	0.1
Manufacturing	8.1	11.9	20.0
Transportation (rail, highway & water)	1.3	1.9	3.2
Other (gen. public, government, etc.)	47.3	64.5	111.8
Totals**	322.2	416.9	739.1

*Source: J.C. Thompson

**All sums may not balance due to rounding off.

#Less than 0.05.

Table 4.2 Percent of Respondents in Each Activity Group Who Designated the Indicated Forecast Period as the Minimum Required for an Adequate Warning Against Adverse Weather*

Activity	Forecast Period 1-5 hours	6-11 hours	12-36 hours	2-5 days	30 days	90 days
Agriculture	2.2	5.0	20.9	26.9	24.0	21.0
Aviation (commercial)	25.0	42.1	18.2	11.4	3.3	
Construction	7.1	18.3	46.0	19.0	6.1	3.5
Communications	5.2	10.3	50.4	28.5	5.6	
Electric Power	28.5	20.0	25.7	10.1	5.0	10.7
Energy (e.g., fossil) Fuels	4.5	14.2	48.0	18.4	14.9	
Manufacturing	25.0	18.0	37.2	10.8	3.2	5.8
Transportation (rail, highway & water)	28.0	19.7	40.8	9.3	1.4	0.8
Other (gen. public, government, etc.)	14.7	17.8	30.4	18.7	9.8	8.6

*Source: J.C. Thompson

warning period.* This implies that the considerable potential economic benefits shown for agriculture are not all associated with short or medium-term weather forecasts (3.5 and 7 hour forecasts and 12, 24 & 36 hour forecasts, respectively). Rather, it argues that a very substantial portion of the potential agricultural benefits are associated with the potential for scientific improvements in long-term forecasts coupled with the desirability of long-term (5 and 30 day and seasonal) forecasts by agricultural users. Though Thompson does not explicitly report on the value of improved forecasts as a function of forecast warning period and user application, he does provide an aggregate analysis (accross all user groups) of the economic value of short-term, medium and long-term forecasts. Discussion with Thompson indicates that he did not explicitly consider the impact of an improved severe storm warning capability similar to that which might be provided by an operational SEOS or STORMSAT. Consequently, his estimate of total gains may be understated and will likely differ from estimates of benefits due to these satellites in activities such as construction, aviation, electric power, and

*In the Thompson study, there is an explicit qualitative difference in weather information which is defined by the forecast warning period: short-range forecasts concern ceiling and visibility at major air terminals, medium-range forecasts involve precipitation predictions for major cities while long-term forecasts involve temperature and precipitation predictions for the U.S. as a whole.

transportation. Figure 4.2 shows that only 40% of the total economic benefits from loss prevention can be achieved with short and medium-term forecasts. Since scientific improvements in weather forecasting are more likely to be achieved in the near future for these two forecast categories, it follows that detailed economic studies of the value of improved weather forecasting should not be limited to agricultural applications alone, but also should be pursued in construction, manufacturing and in the general public area.

Thompson's estimate of the economic value of annual U.S. losses that are preventable from improved weather forecasting rely heavily on a limited survey of weather-caused losses to various user groups. The survey encompasses some 1,300 major agricultural, industrial and commercial organizations in the U.S. Of these, 250 responses were received, resulting in a non-response rate of 78%. The high non-response rate could introduce severe bias into a nationwide estimate of losses and protectable losses. With these survey limitations in mind, the benefit estimates to the U.S. from improved weather forecasting must be regarded as tentative. Additional work is required in the form of microeconomic case studies to substantiate weather forecasting economic benefits. We propose that future economic studies concentrate on the high benefit areas of agriculture, construction, manufacturing and general public applications.

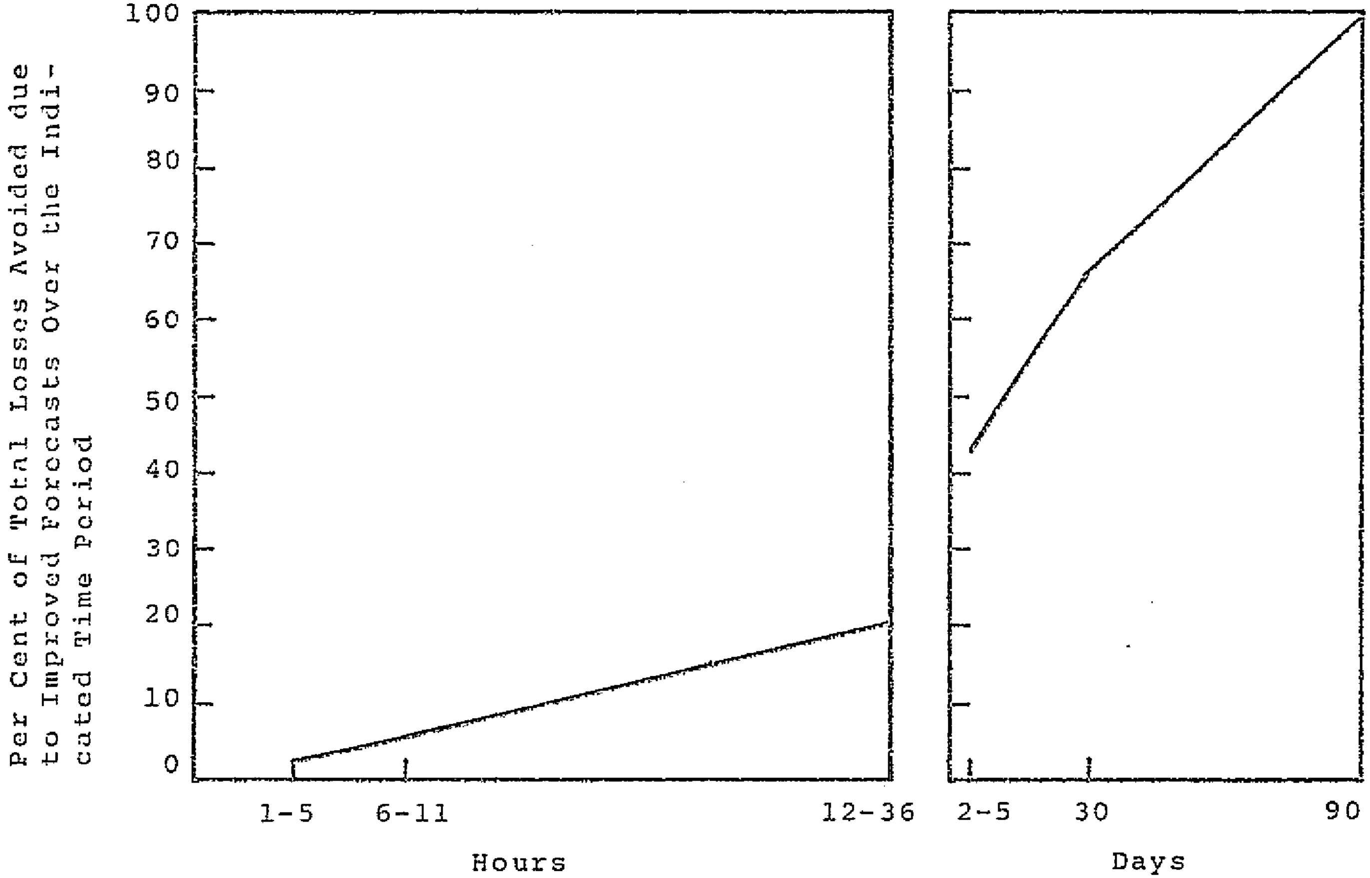

Figure 4.2 Weather-Related Losses Avoidable as a Function of Forecast Period

Adopted from: Thompson, J.C., The Potential Economic Benefits of Improvements in Weather Forecasting, California State University, San Jose, Calif., 1972.

4.2 Case Studies in the Potential Economic Benefits from Improved Weather Forecasting

The government is currently funding a broad range of research which it is hoped will lead to an improved understanding of weather phenomena and to improved weather forecasting capabilities. As part of this research, NASA and NOAA have initiated a broad-based meteorological satellite program. A Synchronous Meteorological Satellite (SMS) is currently in orbit and providing valuable meteorological data. Analyses and evaluations of an experimental Severe Storm Observation Satellite (STORMSAT) and a Synchronous Earth Observation Satellite (SEOS) are currently underway. As part of these ongoing efforts, a preliminary benefit assessment of STORMSAT has been conducted and the results are herein summarized.

The benefit assessment effort briefly examined many potential benefit areas so that the more important areas could be identified. This overview provided rough order-of-magnitude estimates of potential annual savings* so that a ranking of the relative importance of the benefit areas could be accomplished and case studies performed in a logical order of priority. Major potential savings were found to be associated with the utilization of improved severe storm forecasts by the con-

*Potential in the sense that they may be achieved if forecast data are utilized in an optimal manner in user decision making processes.

struction and agriculture industries, savings to a lesser extent were found to result from improved temperature forecasts by the power industry, and savings to a major extent were found to result from snow forecasts when used by urban and suburban agencies responsible for snow removal from highways. Since previous analyses* had considered the former two areas, these have been updated based upon anticipated STORMSAT forecast capabilities and the latter two areas were selected for preliminary case studies.

Most of the benefits which are shown in the following pages are the result of cost savings which are due to the incorporation and use of improved weather forecasts in the decision making process. The benefit estimates are based on meteorological forecasting capability (for example, the probability of snowstorm occurrence given a snowstorm forecast) and not phenomena measurements. The forecasting capability for conventional, SMS** and STORMSAT*** were provided for this study

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*Bhattacharyya, R., Greenberg, J., Lowe, D., Sattinger, I., Some Economic Benefits of a Synchronous Earth Observatory Satellite, prepared by ERIM/ECON for NASA GSFC, September 1974. Bhattacharyya, R., Greenberg, J., Supplement to Economic Benefits of a Synchronous Earth Observatory Satellite (STORMSAT Economic Benefits), prepared for ERIM by ECON, Inc., June 30, 1975.

**SMS forecast capability refers to that capability which results from the incorporation of SMS data with all other available data to produce improved forecasts.

***STORMSAT forecast capability refers to that capability which results from the incorporation of STORMSAT data with all other available data to produce improved forecasts.

by NASA Goddard Space Flight Center. Typical forecast capability data supplied by NASA are illustrated in Figure 4.3. The benefit estimations were not constrained by the operational constraints encountered in the R&D spacecraft. The benefits are the net cost savings that would result if the specified forecast capabilities were achieved and communicated to the users at the appropriate time. User costs associated with the action/no-action decisions (for example, protecting when no storm materializes) are subtracted from the gross savings.

An overview analysis was conducted by ECON to establish rough order-of-magnitude estimates for the benefit areas

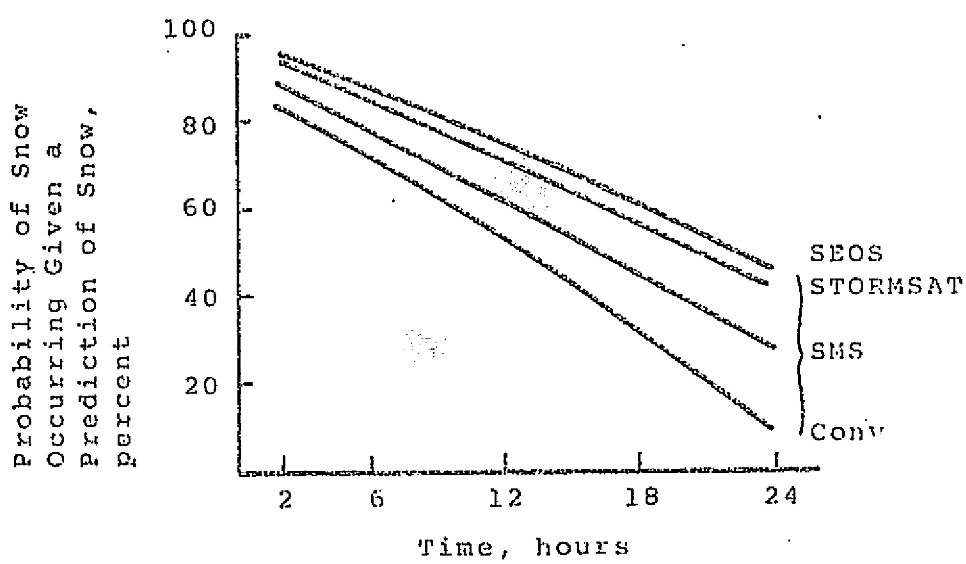
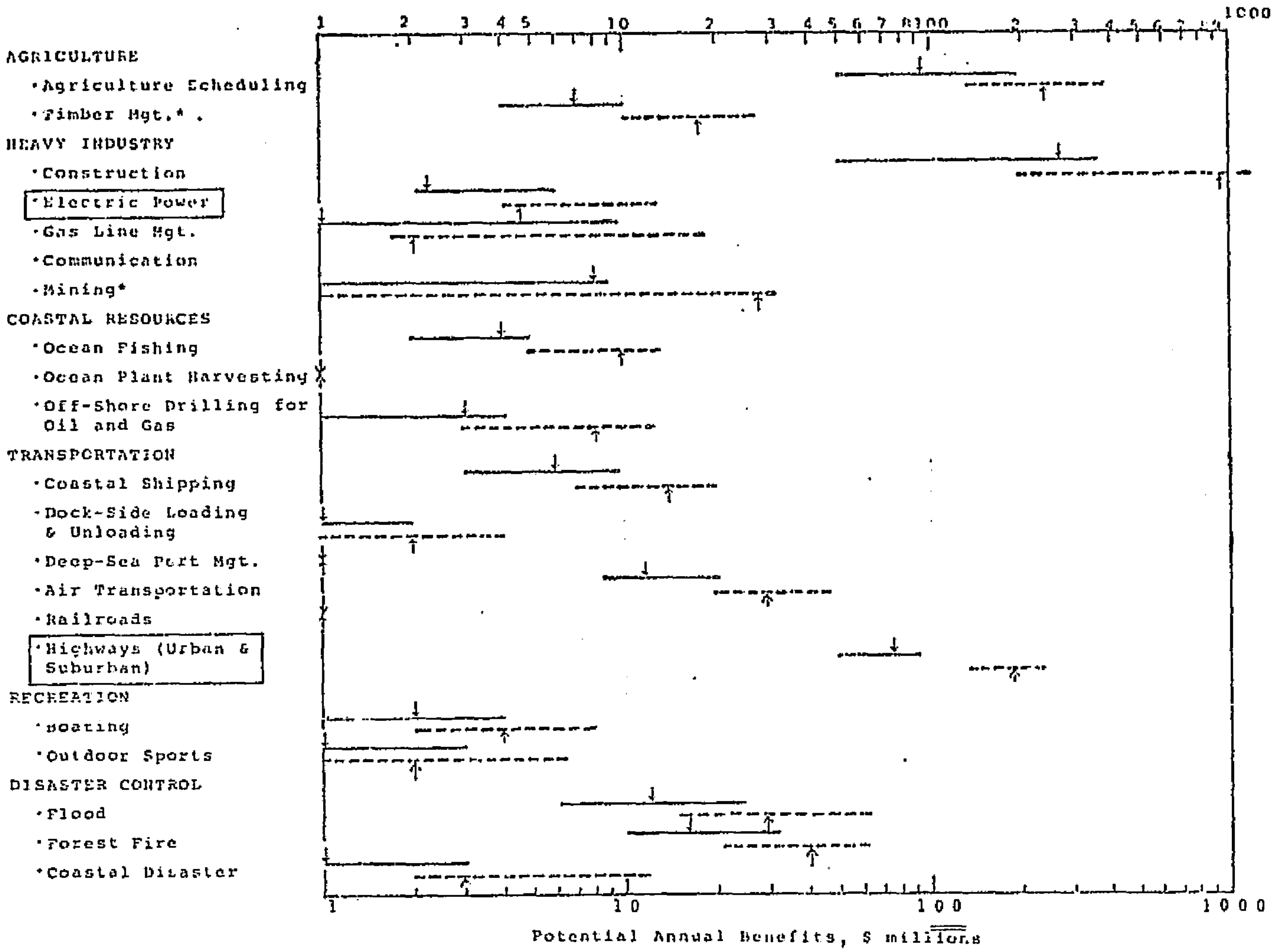


Figure 4.3 Typical Forecast Data - Probability of a Correct Forecast for Snow Over an Area of $1.6 \times 10^5 km^2$ - Data Supplied by NASA

shown in Figure 4.4. Potential annual benefits (savings) that could result from STORMSAT technology and capability are indicated relative to conventional forecasting capabilities and relative to SMS capability (that is, conventional augmented by SMS data). The "boxed-in" benefits (Electric Power and Highways) indicate the results of the preliminary case studies and are discussed in the following paragraphs. The benefits are represented by a "most likely" estimate as well as subjective estimates of the range of uncertainty associated with the benefits.

Many of the applications considered were found to be quite similar particularly with respect to the utilization of storm (thunderstorm, snowstorm, etc.) and frost forecast data. These are applications where a decision-maker must <u>choose between taking or not taking</u> some specific <u>protective</u> action against a future unfavorable weather condition: taking the protective action involves some cost with certainty; not taking the protective action involves escaping that cost but incurring a certain loss <u>if</u> the unfavorable weather condition does in fact occur.

Thus, a construction company can delay pouring concrete and release employees from work when thunderstorms are forecast. A farmer can delay spraying his crops given a forecast for heavy rain. A citrus grower can light smudge pots to protect his fruit from frost. Snow removal crews can be alert-



Notes: *A large part of these benefits are included in the construction industry benefits.

↓ = most likely estimate of STORMSAT benefits relative to SMS.

↑ = most likely estimate of STORMSAT benefits relative to Conv.

↕ = no benefit found

——— = indicates subjective estimate of range of uncertainty of estimates of STORMSAT benefits relative to SMS

- - - = indicates subjective estimate of range of uncertainty of estimates of STORMSAT benefits relative to Conv.

Figure 4.4 Summary of STORMSAT Potential Annual Benefits Showing Most Likely Values and Subjective Estimates of Range and Uncertainty ed and snow removal started earlier. Fishing fleets can be rescheduled when severe storms are forecast. Power line crews can be scheduled in anticipation of storm damage. Optimal scheduling of power generation and distribution can be achieved given temperature forecasts. However, whether a specific protective action should be taken in the event of an unfavorable forecast depends on the accuracy of the forecast, the cost of taking a protective action, and on the loss due to lack of protective action in unfavorable weather.

4.2.1 Case Study - Electric Power Industry

A preliminary case study was performed to evaluate the benefits which might result from improved storm and temperature forecasts to the electric power industry. Potential benefits arise from utilizing improved storm forecasts for scheduling emergency repair crews in an optimal fashion given weather forecasts. The result is a reduction in power outage time and a reduction in revenue foregone because of storm damage to power lines. Potential benefits also arise from utilizing improved temperature forecasts for scheduling power generation and distribution. Errors in scheduling, brought about by errors in estimating demand because of temperature forecast errors, result in the utilization of more costly power generation and distribution facilities. Improved temperature forecasts lead to improved demand forecasts which in turn can be used to optimally schedule power generation and distribution facilities -- the net result is a cost savings to the electric power industry. The resulting potential annual savings are shown in Table 4.3. A detailed analysis was performed for the Pennsylvania-New Jersey-Maryland Interconnection (PJM) based on detailed data provided as a result of their in-house studies. Based on contacts with power companies thoughout the U.S., these detailed data were scaled to achieve the indicated total U.S. benefits.

Power companies currently utilize storm and temperature forecasts on a regular basis in their daily scheduling of operations. Many currently utilize private weather forecasting services. It is apparent that as improved weather forecasting capabilities are developed they will immediately be utilized in the normal course of doing business by the electric power

Table 4.3 Electric Power Industry Potential Annual Benefits from STORMSAT

Benefit Area	Benefits to PJM, $ million		Benefits to Total U.S., $ million	
	Rel. to Conv.	Rel. to SMS	Rel. to Conv.	Rel. to SMS
Speedier Emergency Repairs	.09	.05	.83	.41
Improved Load Forecasting	.36	.18	3.79	1.90
Total	.45	.23	4.62	2.31

industry. In summary, the indicated benefits are relatively small but there is an extremely high likelihood they will be achieved and probably exceeded if the postulated forecasting capability is achieved.

4.2.2 Case Study - Highway Snow Removal

The cost of highway snow removal is highly weather-forecast sensitive. This is evident from the fact that many highway departments are currently utilizing private consultants to provide timely and area-wide specific forecasts of snowstorms. The benefits associated with more efficient snow removal operations resulting from improved scheduling of emergency crews, which in turn results from improved snowstorm forecasts, will be realized both by highway maintenance departments and highway users. The benefits to the highway maintenance departments will accrue as a result of increased efficiency and, hence, lower cost of snow removal operations. The benefits to highway users will be due to:

(1) cost saving for commercial carriers, buses and trucks due to reduction in the time they are held up due to bad road conditions,

(2) a reduction in the number of accidents, thus saving life and property, and

(3) a reduction in the waiting time and consequent inconvenience to individual motorists.

Detailed data were provided by the New York State Department of Transportation, New York State Thruway Authority, Illinois Division of Highways and, in particular, the District of Columbia Department of Highways and Traffic. All currently rely heavily on forecasts for mobilizing their snow removal crews and, for specific forecasts, they employ private consulting firms.

Table 4.4 illustrates the annual expenses and savings which result from different forecast capabilities for Washington, D.C. This set of data has been extrapolated to obtain the total U.S. benefits. The extrapolation, the results of which are summarized in Table 4.5, considers urban and suburban areas separately and considers the extent of improvement in forecast, average annual snowfall, average number of days of significant snowfall, population, land area and annual snow removal expenditures with

Table 4.4 Annual Expenses and Savings Associated with Highway Snow Removal in Washington, D.C.

Item	Expenses, $ thousands			STORMSAT Savings Rel. to- , $ thousands	
	Conv.	SMS	STORMSAT	Conv.	SMS
Snow Removal	228	212	201	27	11
Accidents	385	377	369	16	8
Inconvenience & Production Loss	2960	2620	2380	580	240
Total	3573	3209	2950	623	259

Table 4.5 STORMSAT Potential Total U.S. Savings Associated with Highway Snow Removal		
Item	Savings Rel. to Conv., $ millions	Savings Rel. to SMS, $ millions
Cities	73	29
Suburbs	115	46
Total	188	75

the conventional forecast capability. Since most highway snow removal departments currently use weather forecasts in their scheduling, it is anticipated that improved forecasts will automatically be factored into their operations.

4.3 Recommended Future Economic Studies of Weather Forecasting

The preliminary analyses conducted to date have provided answers to some questions but have left many questions unanswered and have raised many new issues requiring analysis. To a large extent the analyses to date have served to convert "unknown unknowns" into "known unknowns" thus increasing rather than, perhaps, decreasing the need for further satellite-related analyses.

In agriculture, there are two recommended case studies for improved understanding of the source and magnitude of economic benefits from better weather information. Both of these are related to studies that ECON is currently concluding and which we have earlier described. The first case study would assess the impact of improved weather information on improved crop production forecasts, inventory management and distribution. In effect, this case study would build on the previous econometric models that ECON has developed to evaluate the economic benefits from improved crop forecasts and, in so doing, it would introduce into the evaluation a physical process that has a major influence on the accuracy of crop forecasts. The objective of such an analysis would be to determine the extent to which crop forecasts can be improved given improved weather forecasts and, subsequently, to determine the economic value of the resulting improved crop forecasts.

The second recommended case study would focus on weather-related production effects in agriculture. These effects include scheduling such things as planting, spraying, irrigation and harvesting and taking other weather-related preventative actions, for example, frost protection. Losses occur in spraying if unanticipated rains reduce spray effectiveness and if rains come after a period of irrigation. Timing harvests with weather can also have benefits. These effects have preliminarily been estimated to be large and deserving of further study.

In the construction area, ECON has already documented through its past studies substantial annual economic benefits from improved forecasts of severe storms. While the source and magnitude of the potential benefits to the construction industry are well understood, considerable uncertainty remains concerning the technology transfer question. That is, what type of weather data, issued in what format, will the construction industry most readily adapt to in the scheduling of construction operations. To speed up the utilization of improved weather forecasting systems by the construction industry (and thereby to capture the maximum economic benefits), we recommend that a controlled experiment be initiated with at least two construction firms which do not currently use commercial weather services in planning their construction job schedule. The experiment would involve two separate efforts: (1) recording and maintaining records of the daily job plans and the actual job costs and job progress and recording, as well, the daily weather forecast and actual daily weather conditions and (2) after the construction job has been completed, construct a record of the daily progress and operating costs of the construction job by simulating the daily management of the project that would have occurred if weather forecasts had been used to schedule the daily activities of the construction crew. This construction scheduling simulation experiment would permit an objective assessment of the cost and schedule impact of weather forecast on the two construction jobs. It would also facilitate an evaluation of the utility to the construction industry of dichotomous weather forecast information (rain--no rain) relative to probability forecasts. The study would also provide an opportunity to evaluate incremental utility of the experimental (SMS) weather satellite recently launched by NASA in terms of demonstrating to the construction industry the value of improved information. Moreover, the involvement of actual construction industries in the experiment should facilitate the transfer of this NASA-developed technology to the entire construction industry.

Concerning the impact of weather on manufacturing firms, a literature search revealed several studies that examined the use of weather forecasts for sales forecasting, advertising, and inventory control and production planning purposes. In one study,* a regression analysis demonstrated a close relationship between average temperature and retail sales of women's coats. Lost sales during periods of inclement weather, according to one study cited by W.J. Maunder,** are not necessarily counterbalanced by unusually high sales in subsequent periods. The probable impact of lost sales is reduced profit margins because of inventory carrying costs (storage and finance costs) and because of disruptions in the production planning

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*Under, Fabian, "Merchandising Weather," The Conference Board Record, Vol. 19, 1962.

**Maunder, W.J., The Value of Weather, Meutheun & Company, London, England, 1970.

and distribution process. The sales of many manufactured products are likely to be highly weather sensitive; among these are clothing, recreational equipment, sports and gardening equipment, and automotive products such as snow tires, antifreeze, etc. Moreover, the supply of raw materials for certain manufactured products may also be highly weather sensitive. We recommend that a study be conducted to evaluate (1) which manufacturing industries are most sensitive economically to adverse weather and (2) to estimate the economic value of improved forecasts to one or two industries through case study analysis of the inventory control and production planning operations.

We turn now to the general public applications where one area is an obvious candidate for economic study. The problem of air pollution control poses a difficult economic challenge to government and industry alike. The core of the problem is, of course, in the high population urban centers; it is in these areas that the Environmental Protection Agency has established guidelines for maximum acceptable levels of various contaminants such as sulfur dioxide associated with various energy producing systems. Alternative strategies for meeting these goals have been identified and are now the topic of public debate. These include (1) the use of cleaner fuels, (2) the implementation of new technology systems to clean exhaust emissions of the energy production process, and (3) reduced energy consumption. Since local weather conditions such as stagnant air masses, thermal inversion and heavy precipitation markedly impact pollutant levels, it follows that improved forecasting of weather conditions offers an opportunity for economic benefit by choosing the lowest cost strategy for controlling pollution emissions. It is recommended that a case study be initiated to determine the economic value of improved weather forecasts for air pollution control in the New York metropolitan region. Such a study should consider the historical record of interaction of weather and air pollution; the EPA regulation options (e.g., imposition of scrubber technology on power industries) and industrial response in the face of improved weather forecast information--use of cheaper fuels, weather permitting, and more expensive, cleaner fuels in adverse weather conditions.

5.0 A SURVEY OF THE ECONOMICS OF SPACE COMMUNICATIONS APPLICATIONS

5.1 Historical Overview

One hundred years ago, June 2, 1875, Alexander Graham Bell observed in his laboratory a phenomena which led shortly thereafter to the invention of the telephone and a subsequent revolution in communication. Today, there are some 350 million telephones in the world and, in the United States alone on the average business day, some 31 million long distance and 427 million local calls are made. The telephone has spawned an industry which invests $10 billion a year in the United States and operates equipment as diverse as undersea cables and satellites that can relay up to 10,000 voice conversations simultaneously from synchronous orbit.* Most recently, satellite communication capability is being expanded to handle the communications requirements of modern society, governments and of private industries, particularly large corporations and television broadcasting networks that have high data rate requirements.

Table 5.1 lists non-military communications satellite programs through mid-1974. Initial feasibility testing of synchronous communications satellites began in 1963 followed

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*For the Telephone, Half a Bicentennial; The New York Times, June 2, 1975, pg. 27.

Table 5.1 Civilian Communications Satellite Program

Program	Satellites	Launch Date	Remarks
Echo	Echo 1	Aug. 12, 1960	First passive comsat - relayed voice, TV
	Echo 2	Jan. 25, 1964	Passive comsat - joint program with USSR
Telstar	Telstar 1	Jul. 10, 1962	Active repeater comsat
	Telstar 2	May 7, 1963	Active until May, 1965
Relay	Relay 1	Dec. 13, 1962	Experimental comsat
	Relay 2	Jan. 21, 1964	Active until Sep. 26, 1965
Syncom	Syncom 1	Feb. 14, 1963	Communications lost at injection
	Syncom 2	July 26, 1963	In orbit over Indian Ocean and 180° W - used by DOD
	Syncom 3	Aug. 19, 1964	
Intelsat I	F - 1	Apr. 6, 1965	Over Atlantic Ocean - Retired Aug. 21, 1969
Intelsat II	F - 1	Oct. 26, 1966	First TV transmission to Hawaii
	F - 2	Jan. 11, 1967	Transpacific operation - Retired Feb. 20, 1969
	F - 3	Mar. 22, 1967	Transpacific operation - Retired Feb., 1970
	F - 4	Sep. 27, 1967	Transpacific operation - Retired Aug., 1971
Intelsat III	F - 1	Sep. 18, 1968	Failed to orbit
	F - 2	Dec. 18, 1968	Atlantic Ocean service
	F - 3	Feb. 5, 1969	Indian Ocean service
	F - 4	May 21, 1969	Pacific Ocean service
	F - 5	Jul. 25, 1969	Launch vehicle malfunction
	F - 6	Jan. 15, 1970	Atlantic Ocean service
	F - 7	Apr. 23, 1970	Atlantic Ocean service
	F - 8	Jul. 23, 1970	Apogee motor malfunction
Intelsat IV	F - 2	Jan. 25, 1971	Atlantic Ocean service
	F - 3	Dec. 19, 1971	Atlantic Ocean service
	F - 4	Jan. 22, 1972	Pacific Ocean service
	F - 5	Jun. 13, 1972	Indian Ocean service
ATS	ATS - 1	Dec. 6, 1966	First satellite with despun antenna
	ATS - 2	Apr. 5, 1967	Failed to execute second burn
	ATS - 3	Nov. 5, 1967	Color camera, hydrazine station keeping
	ATS - 4	Aug. 10, 1968	Failed to execute second burn
	ATS - 5	Aug. 12, 1969	Spacecraft failed to despin
	ATS - 6	Dec. 30, 1974	3 - axis spacecraft, large antenna
Canadian Telesat	ANIK - I	Nov. 1972	Domestic satellite communications to Canada
	ANIK - II	Apr. 1973	
Domsat	Westar - I	Apr. 13, 1974	First domestic satellite service to U.S.
	Westar - II	Oct. 10, 1974	
Symphonie	Symphonie 1	Dec. 19, 1974	Satellite in orbit awaiting use
Molniya			Russian system placed into service in 1967

Sources:

1. TRW Space Log 1970 - 71
2. LaVean, G.E. and Martin, E.J., "Communications Satellites: The Second Decade," Astronautics and Aeronautics, April, 1974, pp. 54 - 60.
3. "Westar II Gets a Perfect Ride," IEEE Spectrum, November, 1974, p. 22.
4. Hupe, H.H., "Markets for a 'Social Services Satellite'," Astronautics and Aeronautics, February, 1975, pp. 62 - 68.
5. Private conversation with M. Kaplan, Pennsylvania State University, June 4, 1975 .

two years later by the INTELSAT I, Early Bird, satellite. INTELSAT I was operated commercially by the International Telecommunications Satellite (INTELSAT) Consortium created as a result of two international agreements opened for signature in Washington, D.C., on August 20, 1974.* These agreements designated the Communications Satellite Corporation (COMSAT) as manager on behalf of the consortium. Since the launch of the Early Bird satellite which provided the world's first commercial communications satellite service, COMSAT has progressed to the fourth generation of communications satellite, INTELSAT IV, first launched in early 1971. A fifth generation satellite, INTELSAT IV-A is scheduled for launching in 1975. Table 5.2 lists the members of the INTELSAT Consortium.

In addition to the INTELSAT family of communications satellites, NASA has been active in two advanced technology programs involving communications satellites since about the mid-1960s. The first of these programs, designated the Advanced Technology Satellite (ATS) series, had its first satellite, ATS-1, launched December 6, 1966.** Since that time, the ATS family of spacecraft have provided a major test platform for space-based communications experiments. ATS-6, in

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* Comsat Annual Report to the President and the Congress, Communications Satellite Corporation, Washington, D.C., August 27, 1972.

** Hupe, H. H., Markets for a "Social Services Satellite," Astronautics and Aeronautics, February 1975.

Table 5.2 Members of Global Communications System

The International Telecommunications Satellite Consortium (INTELSAT) has established a global operational system with satellites positioned above the Atlantic, Pacific and Indian Oceans. This system is transmitting live television, telephone, telegraph, data and fascimile communications linking six continents. As of July 1, 1973, there were 67 earth stations in 50 countries. It is expected there will be 73 earth stations in 55 countries at end 1973; 84 in 64 countries at end 1974 and 94 in 74 countries at end 1975. As of July 1, 1973, the 83 members were:

Afghanistan	Ecuador	Ivory Coast	Nicaragua	Syria
Algeria	Egypt	Jamaica	Nigeria	Tanzania
Argentina	Ethiopia	Japan	Norway	Thailand
Australia	Finland	Jordan	Pakistan	Trinidad & Tobago
Austria	France	Kenya	Peru	Tunisia
Barbados	Gabon	Korea, Rep. of	Philippines	Turkey
Belgium	Germany, Fed. Rep.	Kuwait	Portugal	Uganda
Brazil	Greece	Liechtenstein	Saudi Arabia	United Kingdom
Cameroon	Guatemala	Luxembourg	Senegal	United States
Canada	Iceland	Malagasy	Singapore	Vatican City
Central African Rep.	India	Malaysia	South Africa	Venezuela
	Indonesia	Mauritania	Spain	Viet Nam, Rep. of
Chile	Iran	Mexico	Sri Lanka	Yemen Arab Rep.
China, Republic of	Iraq	Monaco	Sudan	Yugoslavia
Colombia	Ireland	Morocco	Sweden	Zaire
Costa Rica	Israel	The Netherlands	Switzerland	Zambia
Denmark	Italy	New Zealand		
Dominican Republic				

Source: Department of State, data from World Almanac and Book of Facts, Philadelphia Inquirer, Newspaper Enterprise Associates, N.Y., N.Y., 1974 ed., p.479

particular, has been used extensively for experiments conducted by the Department of Health, Education and Welfare (HEW) in the areas of education in remote areas, including Appalachia, the Rocky Mountains and Alaska, and in a variety of medical communications experiments. The second major experimental program is a joint NASA-Canadian program involving the Communication Technology Satellite (CTS).* Under this program, a 22-state continuing medical educational experiment (APACHE) is planned to deliver audio visuals and telephone feedback beginning in 1976.

Most recently, domestic communications across the continental U.S., Alaska and Hawaii are being provided by a growing Domestic Communications Satellite (DOMSAT) network. Two satellites, Westar I and II, have already been launched by Western Union and are providing coast-to-coast "mailgram" service.** The inaugeration of DOMSAT service marks a radical departure from previous Federal Communications Commission (FCC) policy from that of regulation to that of limited, but progressive, deregulation.***

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* Ibid.

** Westar II Gets a Perfect Ride," IEEE Spectrum, November 1974, pg. 22., and private conversation with F.W. Ziegler, Western Union, Upper Saddle River, New Jersey, June 4, 1975.

*** Sadofsky, M., ed., "This Proceeding is Terminated," Telecommunications, February 1973, p. 21.

In addition to the civilian sector, the Department of Defense (DOD) has directed satellite communications programs for over 10 years. The first operational defense communications satellite system was known as the Interim Defense Communication Satellite Program (IDCSP) which is now renamed the Def Satellite Communications System (DSCS) Phase I.* This system comprised 26 simple, spin stabilized satellites launched between June 1966 and June 1968 into near synchronous, equational orbits. Of the 26 satellites placed into orbit, 11 were still performing satisfactorily as of a year ago. Thirty-six R&D ground terminals were developed to support the DSCS Phase I program and demonstration of the feasibility of military satellite communications. The Phase I system has been in operational use now for several years. The second generation system, DSCS Phase II, began with the launch of two satellites in November 1971, followed by two more in December 1973. Following evaluation, this system went into operation during March 1974. The Phase II satellites are much larger and greatly improved over the Phase I satellites.

During Phase I of DSCS, the United Kingdom entered into a cooperative effort with the U.S. to establish an operational service called Skynet. The system included

*LaVean, G., and Martin, E.J., Communications Satellites: The Second Decade; Astronautics and Aeronautics, April 1974, pp. 54-60.

large fixed ground stations and ship-borne and land mobile terminals. The Skynet II program was initiated in early 1971 with the first launch of Skynet II in January 1974 (this satellite failed to orbit due to a malfunction of the booster).

NATO has also conducted a satellite communications program consisting of several phases with Phase I being conducted between 1967 and 1970.* Phase II started in March 1970, and developed to operational capability during the 1971 to 1974 period. Two satellites were launched into synchronous orbit in March 1970 and February 1971, and were supported by 12 ground stations operating near the capitols of the 12 participating countries. The NATO communications program is now moving into Phase III with a significant increase in the number of ground stations and the addition of large transportable terminals.

Experimental military satellites have included the Lincoln Experimental Satellite (LES) series through which testing has been performed in the VHF and UHF bands. The tactical capability developed through these satellites will be expanded when FleetSatCom is launched in 1976. The FleetSatCom will provide service to military ships, submarines and air craft. The technology in DOD satellites is now focusing on survivable satellite systems.

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* Ibid.

In addition to U.S. military and civilian satellites, a variety of foreign communications satellite systems are being developed. These include the Canadian Telesat System which began operation with the launch of ANIK in November 1972, followed by a second satellite in April 1973.* The ANIK satellites are stationed at 114°W and 109°W longitude and illuminate Canada from the east coast to the west coast and the U.S. border to the far northern areas of Canada. The satellites were built by Hughes Aircraft and launched on the Delta vehicle.

The Russians operate the Molniya system which was placed into service in 1967 to provide telephone and telegraph, radio and television service to points within the USSR as well as connections to overseas points. One of these connections includes Washington, D.C. and provides a direct communications link between the chiefs of state of the two countries.

In a joint venture, the French and Germans launched the Symphonie satellite on December 19, 1974. The purpose of this satellite is to provide communications between France and Germany, and France and its possessions in Africa. This satellite is not functioning but all systems appear ready to begin operation.

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*Ibid.

**Private conversation with M. Kaplan, Pennsylvania State University, June 4, 1975.

Additional systems are being pursued by the Japanese and the Italians. The Japanese currently have two satellites under procurement, one from GE and the other from Philco-Ford. The GE satellite is a 3-axis satellite and the Philco-Ford satellite is a spinner.*

These satellites are being provided to a Japanese manufacturer with guaranteed technology transfer. The Italian program consists of the SIRIO satellite which is a simple spinner.

It is clear from this overview that the U.S. technology predominates free world communications satellites. The extent to which this will remain the case should be an important issue for NASA to consider. In particular, NASA should consider the Federal R&D necessary to provide a technology base required to maintain the desired share of the international telecommunications hardware market.

5.2 Technology Factors and Trade-Offs

Many technology factors and trade-offs must be considered when configuring satellite communications systems. These factors and trade-offs affect both the space portion of the system and terrestrial portion, both individually and in combination, with the result that many compromises in system design must be accomplished.

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*Ibid.

Normally, the starting point of communication system analysis is with the communication demand. Demand is normally specified in terms of number of users, type of communications, (i.e., voice, TV, data, etc.) error rates and many more. It is important to note that the type of data to be communicated may have a significant influence on overall system design. For example, power savings are possible by taking into account the detailed time and frequency characteristics of the information to be communicated. The end result of the specification of demand is the determination of the information bandwidth required for the system. This information bandwidth must be established for all points in the system (i.e., the spacecraft and the various ground terminals to be considered). The information bandwidth requirements must be modified to take into account the specific modulation techniques which are likely to be employed. For example, single sideband, frequency modulation, time division modulation, etc. The different modulation techniques, both on the up and down communication links, have a profound influence on overall system design.

The choice of modulation technique has a direct influence on the power requirement and multiple-access capability of the system. When the combination of satellite power and terrestrial receiving aperture is of prime concern, spread spectrum communication techniques are normally implied which trade off bandwidth for power (i.e., frequency modulation). This has the effect of reducing the transmitter power receiver aperture product for the sake of increased spectrum utilization. Increased spectrum requirements must be matched to spectrum availability which in turn has a direct influence on the part of the spectrum which will be used for the communication system. In general the higher the frequency the greater the availability of spectrum for communications but the more significant the atmospheric affects on communications (for example, the absorbtion effects of rain and humidity on shortwave links). To compensate for the absorptive effects, higher power may be utilized. The choice of frequency is a major design factor because of both atmospheric effects and availability of adequate technology.

The goal of achieving multiple access capability can have significant impact on overall system design. In general the greater the number of users which may have direct access to the system, the more inefficient the utilization of the spacecraft power. This results from the fact that in order to minimize the effects of inter-channel modulation noise either low average power must be utilized with transmitters having high peak power capability (frequency division multiplex) or a large number of time slots must be provided and on average go unused when utilizing frequency division multiplex techniques. The degree of multiple access capability coupled with the desire to communicate with both large and small terrestrial terminals (small in terms of the combination of power, antenna size and number and communication channels) will normally have a profound effect on overall system design and economics.

Major trade-offs between the spacecraft transmitter power and antenna size and ground terminals are possible. For example, spacecraft power may be increased and terrestrial terminal antenna size decreased (for a specified signal-to-noise ratio). A reduction of antenna size implies, however, that the ground terminal transmitter power must be increased (assuming a common transmit and receive antenna) to maintain a specified power density at the spacecraft. Spacecraft and/or ground terminal power may be traded directly with antenna gain. The ratio of utilized bandwidth to information bandwidth may be traded, within limits, with power to maintain a specified signal-to-noise ratio. This implies that increases in power capability may be used to reduce spectrum requirements and thereby squeeze more information into a constrained spectrum space.

The utilization of orthoginal polarization allows re-use of the spectrum. Utilization of narrow-beam antennas on the spacecraft make possible the further re-use of the spectrum. This provides, with limits, a significant angular re-use of the spectrum with tolerable levels of interference. This is accomplished at the sake of complex switch and signal routing and other spacecraft complications.

The above has attempted briefly to outline several of the more important trade-offs which are possible between spacecraft and terrestrial terminals. The combination of the large numbers of variables and the range of the variables make overall system optimization extremely difficult and very important. The importance manifests itself through system capability, costs and revenue generating ability through operational restraints which can significantly influence choices or alternatives for decades into the future.

5.3 Commerce

Substantial economic benefits to the nation from space communications are evident in at least nine application areas. Each of these areas is reviewed in the subsequent paragraphs and recommendations are made for evaluating the potential economic benefits through case study analyses where feasible.

5.3.1 Marine Applications

It is projected that, by 1980, there will be almost 14,000 large ships (greater than 10,000 tons) in service of which 70% will be at sea at any given time. These vessels will carry about 80% of the world ocean-going trade.* As of

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*Baker, J.L., Satellites for Maritime Applications, J. of Spacecraft and Rockets, September 1973, pp. 547-548.

January 1, 1973 the merchant fleets of the world included over 21,000 ships with a capacity of nearly 400 million dead-weight tons.* Each day, an average of 15 ships are damaged or grounded and one in 200 ships are totally lost each year.**

Presently, about 93% of the messages between these ships and shore are carried by CW Morse Code on HF/MF radio. This archaic radio transmission system is both inefficient and unreliable, and since the system requires operators at both the transmit and receive terminals, and since most ships man their radio room for only one watch, delays of up to 6 hours in message delivery are encountered on the average. As a result of the problems encountered in the use of this system, message content between ship and shore averages only about 45 words per day and voice messages are limited to an average of about one 15-minute call per ship per week. The result of these inefficient communications is that it is not possible to make efficient management decisions regarding ship operations.

The use of satellite facilities could greatly reduce delays and result in increased communication traffic with an attendant increase in the efficiency of ship manage-

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*The World Almanac and Book of Facts, The Philadelphia Inquirer, New York, NY, 1974, p 126.

**165th Annual Report, Liverpool Underwriters Association, Liverpool, England.

ment. Figure 5.1 summarizes projected system costs and revenues for a marine communications satellite system. This figure indicates that cumulative system revenues will exceed cumulative system costs by about 1983. The cost to the ship owner for required equipment would be about $14,000 per year per ship with an additional cost of $6,000-$12,000 per year to include a navagational capability. Studies by various agencies have indicated that the benefits of these added capabilities would exceed their costs and, in addition, there is the benefit of increased safety.

Comsat General, in conjunction with other U.S. communications entities, will establish the world's first maritime satellite system with the launch of MARISAT scheduled for late 1975. Two satellites will be deployed in this system, one over the Atlantic and one over the Pacific. Two services will be provided, one in the UHF band (240-400 MHz) for the U.S. Navy and the second, near 1600 MHz, will connect shore stations with commercial ships. Studies by the International Maritime Consultative Organization (IMCO) aim at establishing a fully internationalized maritime satellite system by the early 1980s. Thus, a substantial market on the order of $100 million will exist for ship-board equipment. Whereas the satellite technology for this system appears to be well

*op. cit., Baker, J.L.

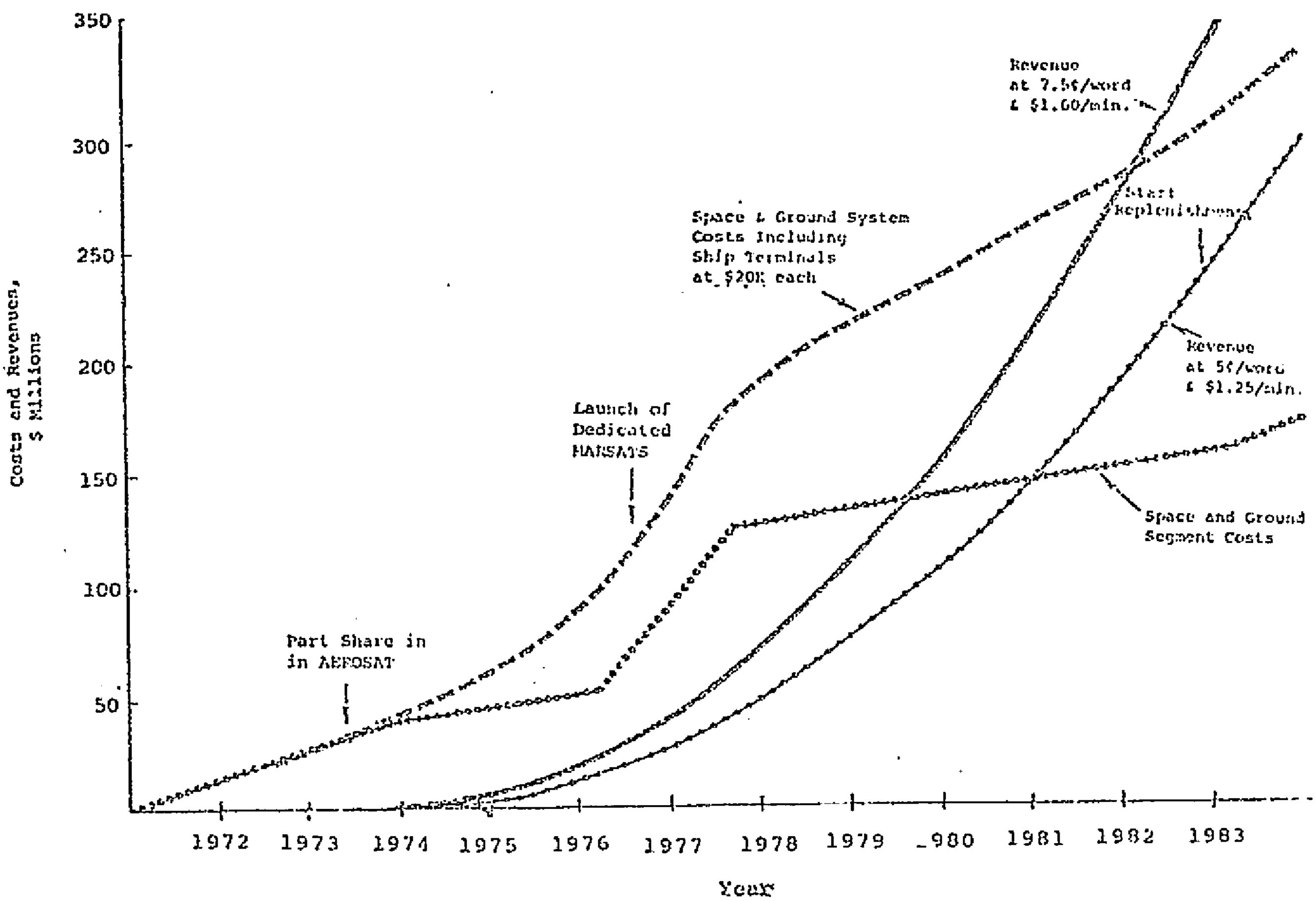

Figure 5.1 Maritime Satellite System Cumulative Costs and Revenues

Source: Baker, J.L., Satellites for Maritime Applications, J. Spacecraft and Rockets, September, 1973, p. 548.

demonstrated and entering the commercial phase, the ship-board equipments will probably continue to develop and could be subject to international competition for supply. The economic impact of the development of low-cost competitive ship-board equipment is properly a concern of NASA from the viewpoint of potential foreign capture of the market and as part of an overall study of the economic impact of foreign penetration into the satellite communications market on the U.S. economy.

5.3.2 Aeronautical Applications

At the present time, transoceanic aircraft carry both VHF and HF communications equipment. VHF range is limited to about 200 miles at an altitude of 30,000 feet (line-of-sight). HF transmissions will propagate over the horizon and are used during the greater part of an oceanic flight. To provide facilities for HF communications, the airlines formed and subsidize Aeronautical Radio Inc. (ARINC). ARINC now provides the communications link between airliners over the oceans and the air traffic control centers (ATCC) and corporate terminals. HF transmissions, however, have limited traffic capacity and communications may be unreliable due to inonospheric disturbances. At the present time, position surveillance of aircraft over the ocean is also unreliable for two reasons: one, because of the variabilities in the

HF link, and two, because of the limited capability of certain navigational systems. With improvement of the communications link between over-the-ocean aircraft and ATCC, position surveillance will be possible using either on-board navigational aids such as inertial navigation systems (INS) or satellite interrogation/transponder systems. The active surveillance of aircraft will enable more efficient use of airspace over the oceans and optimum routing of aircraft.*

With the provision for a position surveillance data link, aircraft status data also can be telemetered to the destination to affect more rapid maintenance turn-arounds. Substantial improvements in communications with aircraft over the ocean and provisions for position surveillance are difficult to achieve, however, by upgrading the existing HF system. The number of available channels is limited by frequency allocations and link reliability is strongly related to assigned frequency. Communications and surveillance services for over-the-ocean aircraft, therefore, can be provided by a satellite system with little or no competition from existing systems.

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*Miller, B.P., The Potential for Development of Civil Vehicle Satellite Traffic Control Systems, RCA Report PRAE-72-TR-008, November 10, 1972.

The present traffic over the Atlantic amounts to some 200 aircraft per day and over the Pacific between the west coast and Hawaii alone is on the order of 100 aircraft per day. These aircraft cost between $2,000 and $5,000 per hour to operate. Therefore, small percentage increases in system operating efficiency can lead to sizeable benefits for the aircraft operators. In the Central East Pacific (CEP) region (west coast to Hawaii), for example, the air route system now consists of four east-west lanes: North, Alpha, Bravo and South. Flight levels at odd thousands from 290 (29,000 feet) to 410 (41,000 feet) are available. Particularly from a fuel consumption point of view, it is very desirable to operate jet aircraft at their optimum altitude and use optimum flight profiles. Frequently, this entails altitude changes enroute. In the present system, during peak traffic hours, it is not possible to accomodate these desires. With active surveillance and a reliable communications link, the system could provide the increased flexibility necessary to accomodate more nearly optimal flight profiles.

In addition to the aspect of increased route efficiency, there is the additional benefit of increased safety. In November 1973, a controller cleared two Boeing 747 aircraft to the same oceanic fix at the same time and altitude. Upon realizing his mistake, he was unable to contact the aircraft in sufficient time to avert a near miss. It is quite possible that a satellite communications system would have prevented this incident.

After some ten years of study, there now exists a joint venture for establishing a developmental aeronautical satellite system (AEROSAT) for the Atlantic region involving participation by appropriate U.S., Canadian and European entities. This system now appears close to reality and will include two satellites placed over the Atlantic beginning in 1977. Each satellite will contain communications channels for operation in the VHF band (130 MHZ) and the L band (1600 MHZ). The two satellites, suitably placed in orbit, will allow for simultaneous use to test position-fixing techniques for possible future air traffic surveillance.

While this is clearly an area for technology development, responsibility for this development now rests with the Federal Aviation Administration (FAA) and is being conducted at the Department of Transportation's Kennedy Center. However, there is again the question of the airborne equipment and the extent to which cost-competitive technology developments will increase the U.S. share of the user market for these products.

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5.3.3 Voice, Video and Data Link

Two broad categories of communications are important in a modern economy: one, transoceanic low-to-medium bandwidth communications, and two, short-range to transcontinental medium-to-high bandwidth communications. In the former category, the role of satellites has been largely to replace undersea cables as a means of providing transoceanic voice communications at substantially reduced costs and to provide a unique capability for a limited number of video channels used primarily for news events and real-time sports broadcasting.

The demand for medium to broadband domestic communications led the American Broadcasting Company (ABC) in September 1965, to request a satellite authorization for network television broadcast distribution. The network requirement for the service which ABC desired is complex in that there is a very high peak in the number of transponders they would use for a maximum of eight hours on Saturdays and Sundays in the fall and early winter. In fact, the continued demand for the real-time broadcast of major sports events has proven to be a driving factor in the design of many satellite systems.

By March of 1971, eight competing basic systems had filed with the FCC to provide domestic communications services. The groups filing included:*

Western Union

AT&T Comsat

GT&E/Hughes

Comsat

RCA Globcom/Alascom

Western Tele-Communications

MCI Lockheed

Fairchild Hiller

It is interesting to note, as shown in Table 5.3, that the lowest capacity satellite in any of the systems proposed equals that of an INTELSAT IV spacecraft and the largest has a capacity 10 times that of an INTELSAT IV satellite. Five potential domestic satellite operators have been authorized by the FCC to proceed with their initial plans. These include: Comsat General/AT&T, Western Union, American Satellite Corporation (ASC) owned by Fairchild Industries, General Telephone and Electronics (GT&E), RCA Global Communications (Globcom), and CML a company jointly owned by Comsat General, MCI Communications and Lockheed Aircraft.

*Greenquist, R.E., First Generation Domestic Satellite Systems, AIAA Paper No. 71-842, July 1971.

Table 5.3 Domestic Communications Satellite Systems *

System	Transponders	Satellites
Western Union	36	3
AT&T/Comsat	72	3
GT&E/Hughes	24	2
RCA Globcom/Alascom	24	2
Comsat	72	3
Western Tele-Communications	24	2
MCI Lockheed	96	2
Fairchild Hiller	240	2

*Source: Grennquist, R.E., First Generation Domestic Satellite Systems, AIAA Paper No. 71-842, July 1971.

The Comsat General/AT&T satellites are similar to the INTELSAT IV and IV-A series. These will service the continental U.S., Hawaii, Alaska and Puerto Rico and will include intra-Alaska service. The Western Union system uses the Westar I and II satellites of a design similar to the Canadian domestic system. It provides service to the Continental U.S., Hawaii and Alaska. Western Union intends to offer a complete line of services through its stations in New York, Chicago, Atlanta, Dallas, and Los Angeles or other customer-owned facilities. The service will include voice, data (low-speed, medium-speed, high-speed), video and facsimile. ASC is evaluating the feasibility of communications transmission in the 12-14 GHz range. In the meantime, ASC will provide services by leasing transponders on the Western Union system for service to New York, Los Angeles and Dallas, and by leased terrestrial facilities for service to San Francisco and Chicago. GT&E, through its subsidiary GTE Satellite Corporation (GSAT), plans a satellite system providing a trunking capability between areas that it serves. The FCC has authorized GSAT to construct five ground stations in Hawaii, California, Pennsylvania, Indiana and Florida. However, because of the restrictions imposed by the FCC, GT&E will provide only message toll telephone service for a period of three years. Two exceptions to this restriction include authorization to carry private line services over its system between Hawaii and the mainland and to carry private line services for the U.S. Government over any part of its system. RCA Globcom and RCA Alascom began domestic satellite communications services in January of 1974 using transponders in the Canadian satellite system to link four ground stations in Pennsylvania, California, and two in Alaska. In the second phase of this program, RCA will launch three satellites, each containing 24 transponders and will provide a network of stations to serve all 50 states. CML plans appear to be directed at the private line and point-to-point commercial market. In contrast to the other systems, the CML concept envisages literally hundreds of antennas of various sizes tailored to meet the communications needs of individual consumers.*

The uses to which domestic communications satellites can be put are many and varied and it is quite clear that the present systems have been designed to service existing communications demands while, at the same time, not excluding the possibility of entirely new types of service. One such new service, CALLFAX, was researched by RCA several years ago. In this system, the operator, who might be a housewife, for example, can call from a library various written

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*op. cit., LaVean, G.L. and Martin, E.J.

materials first to view on a TV screen and then, if desired, obtain a hard copy printout. Under extensions to this system, one can envisage a master (perhaps national) library that could provide complete and immediate access to all public, unclassified written materials. Such a system could truly provide free access to information for all citizens and would be of great benefit to private individuals, corporations and government agencies. While the potential business even from the CALLFAX system was assessed to be very large, a well defined market for such services does not presently exist and the potential market is diffused across a broad spectrum of small-scale consumers. As a consequence of the diffuse market and extremely large front-end investment necessary to start such a system, RCA elected not to proceed.

A second, innovative use of domestic communications satellites has been proposed by Davis.* In this use, it is proposed to provide a TV link for use by state and local governmental agencies with the objective of improving the flow of communications between different levels of government and the diffusion of innovative practices in public administration. It is pointed out that numerous agencies and autho-

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*Davis, R.T., A Modest Proposal for Using Domestic Communications Satellites, Astronautics and Aeronautics, April 1974, pp 62-67.

rities must communicate clearly and frequently to achieve efficient, equitable and innovative government. An experiment in inter-government communications is being conducted by the Metropolitan Regional Council (MRC) in the New York area. By September 1973, a network of 10 operating TV facilities existed and a daily schedule of interactive-TV programs addressed to the teleconference, technical assistance, policy-coordination and training needs of local governments of the metropolitan region began. The U.S. includes 50 state governments, 300 county governments, 18,000 municipal governments and 17,000 townships. The requirement for communications between these governments will increase substantially in the next decade.

Certainly, the basic technology requirements for communications satellites and ground stations are now well demonstrated. However, two areas of concern remain for NASA. The first of these involves the growth of the domestic, international and foreign communications system from two points of view. First, under what scenarios of federal R&D will the technology keep pace with the demand for communication services and what is the role of NASA in this R&D? And second, what federal R&D is necessary for the U.S. to maintain an "appropriate" share of the market for communications hardware and what is the role of NASA in this R&D? The second area deals with the transfer of communications technology to various potential users.

This involves the planning and execution of user-oriented communications experiments such as that discussed above and the development of appropriate user organizations. We recommend that NASA conduct studies aimed at both areas of concern with the objectives of defining the requirement for 1) the establishment of a communications technology base R&D program, 2) the development and conduct of user experiments, and 3) to provide a nucleus for the formation of appropriate user organizations to affect desired technology transfer.

5.3.4 Electronic Mail

The delivery of electronic mail by satellite has already begun with the initiation of "mailgram" service by Western Union using the Westar I and II satellites. The user of this service dictates his message to a local Western Union office where it is encoded and sent to a Western Union office near the point of delivery. At that point, the message is typed out and placed in the local mail for next day delivery. The cost of this service is $2.50 for the first 100 words and $1.00 for each 100, or fraction thereof, words above the first 100. There is an additional $3.00 fee for hand delivery by Western Union.

The extension of electronic mail delivery from the mailgram to the general case of first class mail, however, is fraught with a variety of difficulties. Not the least of these is the varying size of materials to be transmitted.

Several ideas have been proposed. One of these is to require that all mail to be transported electronically be written or typed on a special form which keeps the size of the message within standard margins. A second problem area lies with the ultimate delivery system which, under present proposals for electronic mail delivery, remains the U.S. Post Office. Because of the various agreements which exist between postal workers and the post office, the speed of electronic mail delivery for most routes is not significantly greater than that of current first class mail. Thus, the major area for technology development in electronic mail systems lies at the terminals of the system. That is, in getting the message into the system and then out of the system and to the addressee. It is probably true that improvements in electronic mail will be most significant when individual data link terminals become available as household items.

5.4 Health and Education

5.4.1 Health Care Systems

A variety of health care experiments have already been performed under funding from the Department of Health, Education and Welfare (HEW) using the ATS-6 satellite. With these experiments, HEW has attempted to bring improved medical services to remote areas of the country. This is accomplished through a variety of programs and techniques which basically fit into two categories: 1) Remote diagnosis and 2) medical training. Remote diagnosis is especially important in Alaska where communities as small as 25 to 50 persons may be separated by hundreds of miles or more from the nearest medical facility. Particularly in the wintertime, transportation of individuals from these communities to the nearest medical facility can be difficult, hazardous and expensive. The purpose of the remote diagnosis is two-fold; first, to prescribe treatment and second, to determine the necessity of transport to a medical facility. Without the satellite system, transport of either the patient or the doctor would be necessary, resulting in an extremely high cost of medical care. As a result of the high cost of medical care in remote areas, many individuals go without such services.

Medical training demands up-to-date information and course material to keep the student and practitioner up with the rapidly expanding body of scientific knowledge. The modern medical doctor no longer finds that the knowledge gained in earning his professional degree suffices for his lifetime of practice. Rather, he must continue his medical education to maintain professional competence. Recently, HEW has funded some $3.9 million of telecommunications education and service-related experiments to aid in medical training and one pharmaceutical house now produces and distributes video tapes for continuing education to 450 hospitals.

Hupe* has estimated the potential market for medical satellite services. He cites that over 440,000 persons work as direct medical practitioners and over 1.5 million work in related jobs. Forty thousand doctors graduate each year and enter the profession. There are 248,000 medical students and 400,000 students in related fields attending 1,500 medical schools and 4,500 schools teaching medical science as a part of their curricula. In addition, there are 3,500 medical libraries in 7,000 hospitals within the United States. Medical schools spend an average of $243,000 each on audio-visual aids and hospitals spend an average of $7,000 each per year. In total, medical institutions spend in excess of $100 million per year on audio-visual aids. Thus, there is a considerable potential for savings through improved communication in this area.

Again, we find that the major impediment to the development of improved health care systems using satellite communication is the present set of institutional arrangements. Institutions providing health care services are in general poorly funded and cannot commit to or support the satellite system in the face of more urgent needs. Because of the generally poor and disaggregated market confronting them, industry is not moving to establish systems with the

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*Hupe, H.H., Markets for a "Social Services Satellite," Astronautics and Aeronautics, February 1965, pp 62-68.

full potential possible. We recommend that NASA examine areas of technology in which Federally sponsored R&D might be conducted in order to reduce private risks associated with the development of satellite-based health care systems.

5.4.2 Educational Systems

In the area of education, HEW has recognized that communication satellites can: 1) reduce audio-visual delivery costs by a factor of 10 to 1,000, 2) reach communities isolated both geographically and by lack of communication facilities, 3) share the best educational and informational resources among all people, and 4) advance productivity in the labor-intensive social services area. The most immediate markets for satellite-delivered education will be primarily in nontraditional, outside the classical classroom setting areas including adult education, open university, medical and professional extension courses and corporate training programs. Traditional academic institutions indicate a growing interest in offering nontraditional learning and degree opportunities for the following reasons: 1) many students cannot reach distant classrooms, 2) many students must study at their own convenience because of work or household duties, 3) many students cannot afford traditional education, 4) many students, particularly older ones, fear or dislike the traditional classroom setting and competing with youthful classmates, 5) new traditional facilities are prohibitively expensive, 6) teachers are increasingly expensive, 7) a general national commitment to equal opportunity for education has developed, and 8) a philosophy that learner-directed education is best is spreading.

Fourteen states now have statewide telecommunications networks for education and thirty-two others have set up state agencies for planning and developing such systems. For example, Indiana's network covers 14 cities and 31 campuses. Nebraska has put almost the entire state within the reach of broadcast TV educational courses. And Michigan State University presents 300 courses via TV at the present time. Chicago's TV college has registered more than 100,000 students in the Chicago area. Three schools use the British Open University courses. Present extension programs enroll 375,000 students.

The demand for audio-visual products in education exceeds $1.5 billion per year. Of this amount, colleges spend $320 million per year and Federal audio-visual grants exceed $100 million per year. College film rental charges total $57 million annually. In 1971, educational users spent $22 million on videotape recorders, $12 million for CCTV systems, $11 million for 16 mm projectors, and $5 million for filmstrip projectors. All of these expenditures represent funds which could be diverted to supporting satellite delivery of the same or similar material.*

Thirteen million adults pursue some sort of educational program and 443,000 university graduate students attend part-time. There exists over 100,000 elementary through high schools throughout the country with 51 million students. These schools spend over $1 billion per year on audio-visual instruction.

Once again we see that the potential demand for satellite services is very large. However, development of appropriate systems and penetration of the market will occur only with the substantial investment and over a long period of time. The disaggregated market is particularly difficult for industry to deal with especially since the satellite delivery system itself is a single entity. To this end, HEW has worked toward the creation of a user consortium that will present industry with a single customer or at least act as a wholesaler of communication capacity. The consortium recently formed has former FCC commissioner, H. Rex Lee, as head. At this point, the major area of concern for NASA lies in technology development for low cost systems, especially ground receiver equipment. Since the cost of ground equipment depends to a considerable extent on the nature of the satellite system with which it must interface, we recommend that a systems study be conducted to determine the system which minimizes

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*op. cit. Hupe, H.H.

total costs for providing a service within the institutional constraints that presently exist and are projected into the 1980s.

5.5 Disasters and Emergencies

5.5.1 Disaster Warning

At the present time the National Oceanic and Atmospheric Administration (NOAA) provides severe storm warning over a radio system that covers 90% of the population of the United States. By the mid-1908s however, NOAA feels that they will have to replace the current system with a new system in order to cover 100% of the population. This system would give warning of such diverse disasters as: frost in citrus areas, stockmen's advisories, severe thunderstorms and tornadoes, floods, hurricanes, tidal waves, and possibly earthquake warning. In addition to providing disaster warning, there is also a need for post-disaster communications in order to guide relief operations. Quite frequently land lines are destroyed by the disaster and post-disaster communications rely on amateur radio operators.

NASA has recently funded a study of a disaster warning system which included a study of the satellite feasibility and cost comparisons between satellites and terrestrial disaster warning alternatives.* The concept is to use a

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*Disaster Warning System: Satellite Feasibility and Comparison with Terrestrial Systems, NASA CR-134622, Computer Sciences Corporation, September 1974.

broadcast satellite capable of transmitting warning messages directly into the home or automobile using the UHF band at about 800 MHz. The satellite would use perhaps as many as three spot beams to direct the broadcast at the area of interest. It would provide for disaster warning over the entire 50 states plus portions of Canada, Mexico and the Caribbean. Cost comparisons indicate that the cost effectiveness of a satellite system versus a terrestrial system depends strongly on the portion of the population which is covered by the system. With 90% of the population covered, the land-based system appears to be cost effective. However, at between 90 and 100% population coverage, the space system becomes cost effective. Much work, however, remains to be done in defining the costs and benefits of the desired disaster warning system.

We recommend that a benefit/cost analysis of a baseline and alternative disaster warning satellite systems be conducted in order to determine the desirability of such a system. This study should include a careful consideration of the ground receiver equipment to be used with the satellite equipment since this can be a major driving element in total systems cost.

5.5.2 Search and Rescue

Search and rescue is presently conducted by a variety of participating agencies including the Department of Transportation, Coast Guard, the Department of Defense and others. While each of these agencies perform activities related to search and rescue operations, no single agency accepts responsibility for all search and rescue operations. Inland search and rescue is managed out of Scott Air Force Base in Illinois. Calls requesting search and rescue activities are directed into Scott AFB and from there are disseminated to the appropriate agency for initiation of search and rescue activities. Generally, for downed aircraft this involves engaging the Civil Air Patrol (CAP) to perform the actual search. As of January 1974, the FAA has required all civilian aircraft to carry emergency locator transmitters (ELT). The battery-powered ELT is mounted in a protected area of the aircraft and is activated by extreme G forces. Upon activation, the ELT transmits a high pitch warble tone on 121.5 MHz. Search aircraft use directional antennas to home onto the ELT transmitter. The major problem with this system at the present time is inadvertent activation of the ELT due to such things as hard landings, extreme turbulence and being dropped or roughly handled while out of the airplane. The current volume of ELT activation reports is about 450 reports per month.* During the period of January through April 1975, the CAP used 96 aircraft, a total of 250 hours on 137 sorties searching for ELTs that had inadvertently been activated. These search activities used light planes, mostly single-engine Cessnas

*Personal conversation with Major Doherty, Scott AFB, Illinois, June 6, 1975.

which cost between $10 and $30 per hour to operate, not including the value of the volunteer pilot's time. Certain search and rescue operations, however, go far beyond the mean. As an example, the Air Force spent over $6 million in a search for an aircraft that disappeared with Congressman Hale Boggs on board. This search included the use of SR-71 type aircraft equipped with side looking radar.

The Coast Guard accepts the responsibility for search and rescue operations over all parts of the ocean. Ninety percent of ocean search and rescue, however, is conducted within five miles of the U.S. coast. For this part of the problem, the Coast Guard believes that there is no requirement for a satellite. It is also their belief that the open ocean provides no major problems.

The Canadians have recently shown considerable interest in U.S. developments in search and rescue technology. Particularly because of the harsh Canadian environment, search and rescue in Canada is time-critical. In fact, search and rescue operations in Canada are limited to a finite and reasonably short period after which it is assumed that if the missing persons are not found they can be assumed dead and further search and rescue operations are unnecessary.

Search and rescue satellite systems could take on a variety of forms. In one form, the aircraft ELT, or its equivalent, would be redesigned to receive navigation signals of some sort, for example, LORAN or OMEGA. The position fix received by the ELT would then be retransmitted and received by the satellite which would relay it to the search party. In an alternative system, the ELT would transmit a stable tone and the satellite would make use of dopler shift to obtain position fixing of the ELT. More work needs to be done to define the range of possibilities of search and rescue satellite systems and their costs.

Much data presently exists within the various search and rescue organizations on the cost and manpower requirements consumed for search and rescue activities. However, this information has not been put together as yet into a single source for use in the evaluation of the economics of search and rescue satellite systems. We recommend a study of current and projected search and rescue activities in order to provide such a data base. Then, if this study shows considerable cost-saving potential for search and rescue satellites, we would recommend as a second effort, a benefit/cost analysis of proposed search and rescue satellite systems.

5.6 Tracking and Data Relay

A tracking and data relay satellite system (TDRSS) differs from the above discussed communication systems in that its purpose is to relay data from other satellites to the ground rather than from one point on the ground to another. As such, the reason for a TDRSS is the existence of other satellite systems. A TDRSS telecommunication service could provide the capability to transfer tracking, telemetry commands, two-way voice, digital and image data between ground, and low earth orbiting vehicles. The TDRSS, when operational, would become an integral part of the spaceflight tracking and data network (STDN). As such the TDRSS would perform the same functions as any other network station; that is, transmit signals to and receive signals from earth orbiting user spacecraft and provide data from which user spacecraft ephemerides could be calculated.* The proposed TDRSS configuration would consist of two operational satellites in geosynchronous orbit, placed approximately 130° apart at 41° West and 171° West longitude in orbits inclined 7° or less, and one associated ground terminal located in the continental United States. Currently, it is planned to locate the TDRSS ground terminal at the White Sands, New Mexico area. The ground terminal will have three antennas each approximately 18 meters in diameter. The tracking and data relay satellite will provide two types of communication service, multiple access and single access service. These services will support three types of users: multiple access users, single access S-band users, and single access Ku-band users. The command data rates to the orbiting spacecraft will range

*Tracking and Data Relay Satellite System (TDRSS) Frequency Plan, NASA, Goddard Space Flight Center, document 16151/1-2.3.6/4.9.2, October 1973.

from 100 bps to 10 kpbs and the telemetry and/or digital data rates will range from 1 kbps to approximately 300 Mbps. Image data may be transferred in digital or in analog form on both the forward and return links and voice will be transferred in digital format using a 32 kbps delta modulation technique.

Among the various users of the TDRSS system, the Space Shuttle and the various low altitude earth observation satellites are of prime interest. Among the factors of consideration in the development of a TDRSS system are area of coverage, system reliability and availability, and system cost as compared to alternative systems. In the case of low altitude earth resources satellites, such as the LANDSAT series of satellites, the objective of the satellite system is to obtain high quality multi-spectral imagery. As such, the system data rates can exceed 100 Mbps per satellite. To acquire these data necessitates one of three options: 1) to provide sufficient ground stations such that all desired data can be relayed in real time to one of the ground stations, 2) to provide a mechanism for data storage (such as on-board tape recorders) to reduce the number of ground stations necessary for acquiring full earth coverage, or 3) to provide a satellite data relay system such as TDRSS for real time relay of satellite data to one or more ground stations. Selection of the optimum system involves more than technical factors alone. For example, there is the desire on the part of certain nations to receive and process earth resources data independently. There is also a desire on the part of the U.S. to export hardware for the reception and processing of earth resources data. On the other hand, there is a strong desire for the U.S. to have complete and direct access to all earth resources data as they are obtained. Thus, the final system may include both a TDRSS and additional foreign ground stations.

We recommend a review of TDRSS requirements for each of the several proposed TDRSS users to serve as a basis for various TDRSS/ground station system configurations. We then recommend that an economic model be constructed to facilitate the analysis of the economic impact of proposed alternative implementations of TDRSS on all aspects of the activities of NASA.

5.7 Summary of Issues on Communications

In summary, we can see that potential benefits of communication satellite systems can be very substantial indeed. In fact, with the further development of these systems, it is easy to envisage a rapid and substantial growth of the communications industry. As this growth proceeds, NASA should be concerned with three important areas. First, the development of supporting technology to assure that the growth of the communications industry is not technology limited and to assure that the U.S. share of the hardware market remains substantial. With the advent of competitive foreign communication systems this will become an increasingly important area. Second, NASA should be concerned with the technology transfer from research and development projects to end users. We see that in certain areas the benefits of improved communication services can be very substantially disaggregated and quite diffuse. In addition, the absence of user groups and appropriate institutional arrangements slows the development of these communications services. Particularly affected are the areas of health care and educational communications services. There is a potential for NASA to provide a very significant social service through properly planned experiments which assure technology transfer in these areas. In the case of search and rescue, and disaster warning, this can extend to the development and deployment of an entire demonstrational system. Third, NASA should be concerned with the development of communication systems for the optimization of its own activities. To this extent, a careful analysis of the potential economic impact TDRSS systems should be performed.

6.0 NOTES ON INSTITUTIONAL ARRANGEMENTS

Many projects or activities, because of cost, risk or other factors, are either beyond the capacity of a single individual or organization, or can be enhanced by the joint participation and mutual cooperation of a group of individuals or organizations. When this is the case, the environment is set for the formation of an institutional arrangement consisting of and/or for the benefit of the affected parties. Institutional arrangements exist in the government, in commerce and between individuals. In general, we find that the nature of each arrangement depends on who the affected parties are and where they are located (government, commercial sector, etc.). In regard to NASA R&D, institutional arrangements can play a major role in technology transfer, in this case from NASA to the user. This can be accomplished through the institutional arrangement in a variety of ways; for example, by providing educational services, by providing technical or other services beyond the capacity of the users or not economic for the users on an individual basis, by dissemination of information to the users, or by pooling risk inherent in the technology transfer process. In a broader sense, NASA itself can be thought of as an institution with the purpose of serving U.S. citizens in general and the aerospace industry in particular through the development and implementation of aerospace technologies.

Three general issues arise under the heading of institutional arrangements. These issues include: 1) payback for Federal R&D and for services rendered, 2) the development and use of institutions to affect technology transfer from the R&D agency to the users, and 3) the purpose of benefit/cost analysis in the framework of institutional arrangements for affecting technology transfer to users. These issues are reviewed briefly below.

We consider first the issue of payback for Federal R&D and the provision of services. The nature and extent of payback for Federal R&D and services depends on the nature and extent of the R&D or service rendered. Certainly part of this issue must deal with the question of who benefits from the activity pursued. In some cases it is apparent that essentially all citizens will benefit from a particular activity. In fact such is the case in the development of a LANDSAT system for the purpose of improving agricultural crop inventories and forecasts. The benefit of this activity can be measured using tools of economics. Assuming that the total benefits to the nation exceed the costs for pursuing the development and operation of such a system by a reasonable margin, it is then appropriate for the Federal government to pursue this activity. The question of cost recovery is now essentially irrelevant. Since the purpose of the Federal government is to serve the citizens of the United States, the pursuit of activities which improve the net standard of living of all citizens should be acceptable by all citizens. The funding of such programs can properly obtain from tax revenues which are collected in a more or less equitable manner from among those individuals who share in the benefits of the activity. Surely, an individual should be concerned about his net material status. However, his dispersement of money to achieve that status, that is, the question of where his money goes, should be an irrelevant issue.

In the event that the R&D or service activity benefits only specific individuals and even perhaps at the cost of others, the issue of who pays to support these activities is somewhat more complex. Again, the first and crucial point is whether the total benefits from the R&D project or service exceed by some margin the total costs for that activity. If so, then we can assume again that it is viable to the government to undertake this activity. However, now we must be much more concerned over the distribution of costs for the support of this activity than in the case where essentially everyone benefits. For example, consider an activity whose purpose is to develop improved weather forecasting techniques which will enable increased efficiency in the construction industry. The beneficiaries of this activity will be primarily the construction companies who make use of the improved meterological information. Suppose for the moment that these benefits are not passed on to the consumers of the construction company's products. Then it would follow that the construction companies should be willing to bear the total cost for developing and operating this system which provides the improved meterological information (assuming that there is a net benefit to be obtained from this activity). In effect, one way of achieving an equitable distribution of costs, is to levy increased taxes upon the construction industry. In theory, these increased taxes would offset the cost of development and maintenance of the meteorological service.

It should be pointed out here that the development and implementation of many systems incure costs beyond simple monetary costs. These costs can include increased pollution, increased noise and increased risk of disease or fatality to the exposed individuals. Again, if in the broad sense of the word the benefits still exceed the cost by some acceptable margin, the project or service is a viable one. Now, however, mere recoupment of monetary costs through increased tax burdens is, in general, insufficient to offset the total cost to society. In this case, the benefiting parties should be willing to compensate other members of society for the disbenefits of the activity which they incur. This notion justifies the levy of increased tax burdens, even beyond recoupment of basic systems costs, and compensation to other members of society through commensurate reductions in their tax burden.

Under certain circumstances, a discreet service might be rendered to a particular individual or individuals. An example of this might be the provision of transoceanic telephone service. In such a case it is certainly reasonable to expect that the user would bear at least the marginal cost of using the system. That is, that he should be willing to pay for the increased cost of maintaining the system due to his use of the system. There nonetheless remains the issue of who should pay the fixed system cost. That is, whether these costs should be amortized across system users or whether they should be borne in a more general way, for example, from general tax funds. The resolution of this question is complex and depends upon the specific service being offered and the extent to which national interests can be served by underwriting the service to some extent. An example of a service which is underwritten by the Federal government is the U.S. Merchant Marine. The U.S. Merchant Marine fleet is underwritten by the Federal government to assure that such a service will exist in time of need. Many such political reasons can exist which make it undesirable to attempt to recover all fixed system costs through amortization across various system users.

In summary, recoupment of Federal R&D or service activity costs should be considered on an individual project basis. These considerations should certainly include the benefits to be derived from the project and their distribution across all U.S. citizens, and the total activity costs, not only monetary, but other real and perceived costs as well. A consideration of national objectives and political goals is also necessary.

We turn now to the issue of appropriate institutional arrangements to affect technology transfer from the Federal R&D agency to the ultimate user. In many cases, institutional arrangements can have a profound effect on the extent and efficiency of technology transfer and implementation. Consider for example the potential dissemination of audio-visual material by satellite for health care and education. Despite the sizeable ultimate market for these services it must be recognized that each individual consumer constitutes only a tiny fraction of the total market. Thus, an industrial organization which might pursue the development of a satellite dissemination system finds itself confronted with a highly disaggregated and diffuse market for its services. Yet the service, a satellite, must be supplied in whole or not at all. As a result, such projects are generally evaluated as high financial risk activities with potentially long pay-back periods. That is, they are characterized by an exceptionally long period of market development.

In point of fact, Western Union has proposed a low cost health care and educational services satellite system.* However, the viability of this service will depend upon the extent to which Western Union is capable of demonstrating that the proposed service is in fact a low risk venture. Because Western Union is a regulated industry, they will not be permitted to proceed with hardware procurement for such a system until such time as they have demonstrated to the satisfaction of the Federal Communications Commission the economic viability and profitability of such a venture. In this case, the controlling institutions of the Federal government are at work to impede the transfer of technology from R&D program to user. To promote technology transfer in a case such as this, it is necessary to create an institution either of the Federal government or at least form a consortium of users in order to present an aggregated and unified marketplace for the proposed service. In the case of health care and educational systems cited above, the Department of Health, Education and Welfare (HEW) has already fostered the creation of such a user consortium. (See Issues on Communications, Section 5.0.) To the extent that institutional arrangements may be necessary to assure the transfer of technology from the R&D stage to end user, NASA should be prepared to act as a nucleus for the development of these arrangements.

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*Private communications with Ziegler, F.W., Western Union, Upper Saddle River, N.J., June 4, 1975.

Clearly, three often independent groups may be involved in the development and utilization of a new technology. These include the sponsoring R&D agency, the implementing industrial organization and the end user. In the cases where NASA is the sponsoring R&D agency, it should also be prepared to act as a nucleating agency for the formation of institutional arrangements to affect ultimate technology transfer to the user.

Finally, it is appropriate to consider the role which benefit/cost analysis plays in the selection and management of R&D projects and in the ultimate technology transfer to the user. Benefit/cost analysis developed in the 1950s and early 1960s through the efforts of various operations research organizations, primarily to obtain measures of cost-effectiveness in military expenditures. Since the early 1960s, the application of benefit/cost analysis has spread to a variety of non-military Federal agencies where it is presently used for project selection both within the agencies and, increasingly, within the Office of Management and the Budget. It is now well recognized that benefit/cost analysis can be used as a tool for R&D project selection; a variety of economic tests may be applied to determine if a specific R&D project should be undertaken. These basically amount to obtaining an assurance that the benefits of the project at least exceed the cost by some margin. It is unfortunate that benefit/cost analysis of many technical projects ends at this point. Beyond project selection, benefit/cost analysis holds a potential for aiding in program management and as an incentive for technology transfer.

In the area of program management, we note that a variety of programatic decisions are made frequently throughout the period of a project. Often, these decisions can affect ultimate technical achievements and economics of the projects. These decisions can be aided through the use of such tools as risk analysis and decision theory. The considerable extent to which risk analysis has become a management tool used in the commercial sector has led to the development of a variety of computer programs that simplify the use of risk analysis considerably. Two such programs with considerable circulation are RISKNET and PERT. Although equivalent programs for use in decision analysis do not currently exist, the use of decision analysis as a management tool is increasing.

Technology transfer to the end user depends not only upon technical success of an R&D program but often requires also that a technology demonstration be provided to assure that an acceptable perceived level of risk exists. Thus, even in the early phases of R&D program formulation, users should be involved to orient the technology development. Generally, in the R&D phase this involves interaction between the research agency and appropriate user institutions. A primary function of the user institutions here is to indicate to the research agency those technological developments which they consider beneficial. Then as a part of the project selection process and subsequent project management process, the performance of continuing benefit/cost analyses should be done in concert with the user institutions. This process assures members of the user institution that projects being completed are in fact ready for an appropriate for technology transfer. Frequently it may be desirable to include as a part of the R&D program an operational demonstration of the developed technology obtaining guidance from user institutions. This process has the effect of further reducing user risks and providing an even more concrete demonstration of the benefits of technology transfer.

In summary, we find that proper institutional arrangements are an important component of technology transfer from R&D project to end user. We find, furthermore, that past projects have not always adequately emphasized the need for proper institutional arrangements. It is especially true that institutional arrangements in the early phases of R&D project selection and project management need greater emphasis. If we accept the fact that Federal R&D should be to the benefit of all citizens of the United States, it then follows that we should be intimately concerned over the eventual transfer of these technology developments to end users and the appropriate implementation of the developed technologies. To the extent that institutional arrangements are responsible for accomplishing these end objectives, NASA should give careful consideration to the institutional arrangements necessary to capture the public benefits of its R&D efforts. Frequently, this will involve NASA acting as a nucleating agency to assure the development of proper institutional arrangements.

APPENDIX A

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