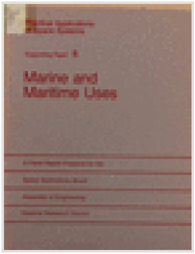

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1974 SUMMER STUDY ON PRACTICAL APPLICATIONS OF SPACE SYSTEMS

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(July 1974)

PRACTICAL APPLICATIONS OF SPACE SYSTEMS

Supporting Paper 8

MARINE AND MARITIME USES

The Report of the
PANEL ON MARINE AND MARITIME USES
to the
SPACE APPLICATIONS BOARD
of the
ASSEMBLY OF ENGINEERING
NATIONAL RESEARCH COUNCIL

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PREFACE

In November 1973, the National Aeronautics and Space Administration (NASA) asked the National Academy of Engineering* to conduct a summer study of future applications of space systems, with particular emphasis on practical approaches, taking into consideration socioeconomic benefits. NASA asked that the study also consider how these applications would influence or be influenced by the Space Shuttle System, the principal space transportation system of the 1980's. In December 1973, the Academy agreed to perform the study and assigned the task to the Space Applications Board (SAB).

In the summers of 1967 and 1968, the National Academy of Sciences had convened a group of eminent scientists and engineers to determine what research and development was necessary to permit the exploitation of useful applications of earth-oriented satellites. The SAB concluded that since the NAS study, operational weather and communications satellites and the successful first year of use of the experimental Earth Resources Technology Satellite had demonstrated conclusively a technological capability that could form a foundation for expanding the useful applications of space-derived information and services, and that it was now necessary to obtain, from a broad cross-section of potential users, new ideas and needs that might guide the development of future space systems for practical applications.

After discussions with NASA and other interested federal agencies, it was agreed that a major aim of the "summer study" should be to involve, and to attempt to understand the needs of, resource managers and other decision-makers who had as yet only considered space systems as experimental rather than as useful elements of major day-to-day operational information and service systems. Under the general direction of the SAB, then, a representative group of users and potential users conducted an intensive two-week study to define user needs that might be met by information or services derived from earth-orbiting satellites. This work was done in July 1974 at Snowmass, Colorado.

For the study, nine user-oriented panels were formed, comprised of present or potential public and private users, including businessmen, state and local government officials, resource managers, and other decision-makers. A number

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*Effective July 1, 1974, the National Academy of Sciences and the National Academy of Engineering reorganized the National Research Council into eight assemblies and commissions. All National Academy of Engineering program units, including the SAB, became the Assembly of Engineering.

of scientists and technologists also participated, functioning essentially as expert consultants. The assignment made to the panels included reviewing progress in space applications since the NAS study of 1968* and defining user needs potentially capable of being met by space-system applications. User specialists, drawn from federal, state, and local governments and from business and industry, were impaneled in the following fields:

Panel 1: Weather and Climate
Panel 2: Uses of Communications
Panel 3: Land Use Planning
Panel 4: Agriculture, Forest, and Range
Panel 5: Inland Water Resources
Panel 6: Extractable Resources
Panel 7: Environmental Quality
Panel 8: Marine and Maritime Uses
Panel 9: Materials Processing in Space

In addition, to study the socioeconomic benefits, the influence of technology, and the interface with space transportation systems, the following panels (termed interactive panels) were convened:

Panel 10: Institutional Arrangements
Panel 11: Costs and Benefits
Panel 12: Space Transportation
Panel 13: Information Services and Information Processing
Panel 14: Technology

As a basis for their deliberations, the latter groups used needs expressed by the user panels. A substantial amount of interaction with the user panels was designed into the study plan and was found to be both desirable and necessary.

The major part of the study was accomplished by the panels. The function of the SAB was to review the work of the panels, to evaluate their findings, and to derive from their work an integrated set of major conclusions and recommendations. The Board's findings, which include certain significant recommendations from the panel reports, as well as more general ones arrived at by considering the work of the study as a whole, are contained in a report prepared by the Board.**

It should be emphasized that the study was not designed to make detailed assessments of all of the factors which should be considered in establishing priorities. In some cases, for example, options other than space systems for accomplishing the same objectives may need to be assessed; requirements for

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*National Research Council. *Useful Applications of Earth-Oriented Satellites, Report of the Central Review Committee.* National Academy of Sciences, Washington, D.C., 1969.

**Space Applications Board, National Research Council. *Practical Applications of Space Systems.* National Academy of Sciences, Washington, D.C., 1975.

institutional or organizational support may need to be appraised; multiple uses of systems may need to be evaluated to achieve the most efficient and economic returns. In some cases, analyses of costs and benefits will be needed. In this connection, specific cost-benefit studies were not conducted as a part of the two-week study. Recommendations for certain such analyses, however, appear in the Board's report, together with recommendations designed to provide an improved basis upon which to make cost-benefit assessments.

In sum, the study was designed to provide an opportunity for knowledgeable and experienced users, expert in their fields, to express their needs for information or services which might (or might not) be met by space systems, and to relate the present and potential capabilities of space systems to their needs. The study did not attempt to examine in detail the scientific, technical, or economic bases for the needs expressed by the users.

The SAB was impressed by the quality of the panels' work and has asked that their reports be made available as supporting documents for the Board's report. While the Board is in general accord with the panel reports, it does not necessarily endorse them in every detail.

The conclusions and recommendations of this panel report should be considered within the context of the report prepared by the Space Applications Board. The views presented in the panel report represent the general consensus of the panel. Some individual members of the panel may not agree with every conclusion or recommendation contained in the report.

PANEL ON MARINE AND MARITIME USES

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Only the fact that the U.S. Coast Guard, the U.S. Navy, the National Oceanic and Atmospheric Administration and the Maritime Administration have active programs to defend in the fields considered by this Panel precluded their participation as full members of the Panel.

INTRODUCTION

Covering more than two-thirds of the earth's surface, water has a fundamental impact on the welfare of mankind, if not on its very existence. The oceans dominate the earth's weather systems and are the source of vast quantities of food and other material resources. Moreover, ocean commerce is of crucial importance to man's capacity to maintain or enhance the way of life he now enjoys. U.S. maritime commerce, as well as world commerce, doubles every ten years — a striking indication of the increasing necessity for nations to supplement their natural resources and manufactured products with those from other areas of the world.

Within its broad subject, the Panel on Marine and Maritime Uses perceives the scope of its concern to embrace activities related to: (1) better understanding, control, and use of the ocean's biological and physical processes for food and energy production and ship design purposes; and (2) providing navigation, communication and data transmission technological aids which improve efficiency and enhance safety in maritime operations. These areas of concern are recognized in the NASA Earth Observations Program, Earth and Ocean Physics Applications Program, and are reflected in NASA's goals and objectives with respect to communication and position determination. The Panel has examined the general areas within its scope of study and concludes that three broad areas should receive major consideration: (1) monitoring of marine environment, (2) position determination, and (3) communication. Monitoring covers physical and biological processes within marine environment as well as shipping, fishing, and related maritime activities. Communication is viewed as a vital function in itself and also as an aid to monitoring, position determination, and navigation.

FOLLOWUP AND EVALUATION OF 1967-68 STUDY

APPLICATIONS TO DATE AND PROJECTED FOR NEAR FUTURE

The Panel on Marine and Maritime Uses finds that its scope includes certain phases considered previously by the Panel on Oceanography, the Panel on Points-to-Point Communication, and the Panel on Navigation and Traffic Control of the 1967-68 study*.

To a remarkable extent the observations and recommendations made by the Panel on Oceanography in the 1967-68 study remain valid today. It noted the need for measurements of wind, waves, currents, tides, and biological activity over the world's oceans, the usefulness of monitoring pollutants, sedimentation, shore erosion, storm surges, and wave diffraction in the coastal zone, and the benefits expected to accrue from these observations. The Panel on Points-to-Point Communication foresaw the need to collect small amounts of data from many buoys, ships, and fixed platforms.

Much work has been done since 1968 to develop new and improved instruments to make these measurements. For example, radar altimeters have continued to improve in accuracy until they now measure short-wavelength undulations of the geoid to an accuracy of 30 centimeters. By the end of the present decade, 10 centimeter measurements will be possible, and this accuracy is needed. Distortion of the altimeter's pulse provides information on average wave height. This information will become more accurate as the altimeters improve. Sea surface temperature is routinely measured to $\pm$ 1.5° C over cloud-free areas of the ocean. Passive multifrequency microwave radiometers are now being flown and it is hoped that they will provide measurements of sea temperature in cloudy areas with an accuracy of about 2° to 4°C, surface windspeed, and atmospheric water vapor content. Multispectral sensors have been operated in space and have permitted determination of features that are needed by coastal planners, such as surface waves, internal waves, pollution, sediment, coastlines, and depth of shallow water. Operational systems that interrogate drifting and fixed data stations, platforms, and ships will soon be available. In order that the position of

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*National Research Council. *Useful Applications of Earth-Oriented Satellites: Report of the Panel on Oceanography* (Panel 5), *Report of the Panel on Points-to-Point Communication* (Panel 7), and *Report of the Panel on Navigation and Traffic Control* (Panel 11). National Academy of Sciences, Washington, D.C., 1969.

these stations may be determined, they should also receive and relay position-fixing signals. Imaging microwave radars record individual ocean waves and may provide wave directional spectra, although comparisons with a measured spectrum are yet to be made. Microwave scatterometers are expected to measure ocean surface winds, but the fundamental interpretation of the data has been a continuing source of controversey. Three ocean-color imaging spectrometers (two for aircraft, one for satellites) have been developed by NASA but have not yet been used in an extended experimental program. In summary, it appears that within this decade refinements of these instruments will meet the user needs that they address.

Of three research and development recommendations in the 1967-68 study report by the Panel on Navigation and Traffic Control,* one that is relevant to the work of the Panel on Marine and Maritime Uses involves radio propagation. Since 1967 there have been a number of experiments and test programs performed using the NASA Applications Technology Satellites -- ATS-1, ATS-3, and ATS-5. Initially, the experiments consisted of sending messages by teleprinter and voice at VHF radio frequencies via ATS-1. Signal quality, error rate, antenna gain and power output were measured and compared. Some line-of-position navigation experiments were conducted. As ATS-3 and ATS-5 became available, they also were used in tests. Ships provided by the U.S. Coast Guard (USCG) and the merchant ship *Santa Lucia* participated in these test programs. The experiments with the *Santa Lucia* represented the first involvement of the U.S. Maritime Administration (MARAD) in the use of satellites to improve ship management and operation. An early study of maritime satellite systems was sponsored jointly by the Office of Telecommunications Policy, MARAD, the Department of Transportation (DoT) and the USCG. This study, completed in late 1970, became the foundation for the United States positions on maritime satellite frequency allocation at the International Telecommunication Union's World Administrative Radio Conference for Space in 1971.

Strong needs expressed by the U.S. and other maritime nations led the Conference to allocate frequencies exclusively for a maritime satellite service in the radio frequency band between 1535 and 1660 MHz (L-band). An additional 2 MHz was allocated for joint use of the maritime and aeronautical communities for such applications as search and rescue. These frequency allocations are much greater than the total radio frequency spectrum otherwise available to the maritime community.

Lack of a spacecraft with an adequate L-band capability delayed early experimentation with satellite maritime communication and navigation systems. ATS-5 was equipped with an L-band transponder, but failed to achieve stabilization of its antenna system. It was possible nevertheless to operate an at-sea demonstration using ATS-5 in 1970. Under MARAD sponsorship, teleprinter messages were exchanged between company offices and the merchant ship *ESSO Baltimore* using the L-band capability of ATS-5.

Following this limited demonstration, MARAD decided to initiate a multiple-ship experiment in communications and navigation. Nine U.S. merchant ships were selected to participate. Because an integrated navigation-communications approach was desired, two satellites, ATS-3 and ATS-5, were used. The C-band

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Report of the Panel on Navigation and Traffic Control, 1969, p. 84.

(4 to 6 GHz) frequencies available on these spacecraft provided data and position determination capability in both the Atlantic and Pacific Oceans. In addition, a Maritime Coordination Center was established at the MARAD National Maritime Research Center, King's Point, N.Y., to provide interfaces with shipping companies and participating agencies. Services demonstrated to shipping companies included shipping management, data processing, and other services.

At-sea experiments using about 800 hours of satellite time were carried out from February to August, 1973. Digital data for communications and position determination were provided. Valuable experience was gained by the participating companies in developing both ship equipment and new ship management concepts.

In 1972 a communications experiment was conducted for a two-month period involving the *Queen Elizabeth II*, the Communications Satellite Corporation (COMSAT), and a satellite belonging to the International Telecommunications Satellite Consortium (INTELSAT). The ship operated in passenger cruise service in the Caribbean, across the North Atlantic, and in the Mediterranean. Voice, teletype, and facsimile information were transmitted successfully.

During a four-month period in 1973 an experimental program by COMSAT with the medical ship *Hope*, located in Brazil, was conducted through an INTELSAT satellite. In addition to using voice, teletype, and facsimile, medical personnel on board the *Hope* used slow-scan television for consulting, in real-time, with medical professionals in the United States. This new capability was enthusiastically endorsed by the *Hope*'s medical personnel.

The experience gained from the aforementioned C-band tests has been used to plan ATS-6 experiments for 1974-75. Although maritime experiments were not initially included in NASA plans for the ATS-6, they have now become an important part of the program. Under MARAD sponsorship, two U.S. merchant vessels will be fitted with L-band ship terminals representative of what might be used in early operational systems. Experiments will include reception and transmission of voice, data, facsimile, remotely sensed data, and experiments with position determination techniques. MARAD's Maritime Coordination Center will be upgraded and again will support the experimental effort. Experiments are also planned in which the USCG and a European Space Research Organization (ESRO) ship will use ATS-6 for various communication modes and for position determination. In addition, an L-band emergency buoy for distress alerting and location will be evaluated.

Interest shown in maritime satellite communications both in the U.S. and in other countries has encouraged COMSAT General Corporation (a subsidiary of the Communications Satellite Corporation), Radio Corporation of American (RCA), Western Union International (WUI) and International Telephone and Telegraph (ITT), to announce the implementation in mid-1975 of commercial satellite maritime communication services in the Atlantic and Pacific Ocean areas using a satellite system called MARISAT. Although the amount and type of service for the early years of the system must be limited because of restrictions arising from concurrent government use of the satellites, it appears that MARISAT will provide a service adequate to meet the communication needs of shipping companies. Experience in using it will permit the development of procedures and techniques for future follow-on systems.

Several series of experiments using a variation of side-tone ranging developed by the General Electric Company (GE) have been conducted from 1968 to the present. The technique used is called "tone-code ranging." It has been used primarily with voice-equivalent channels on ATS-1 and ATS-3 at VHF (130 to 150 MHz), and is a means of measuring the distance from the satellite to the ship using a voice channel at the same time that the channel is being used to transmit information by voice.

At-sea tests using U.S. merchant ships, buoys, and USCG ships have provided considerable data from which it can be concluded that accurate positions of ships and other marine vehicles can be obtained from concurrent ranging through two appropriately located geosynchronous satellites. Employing two satellites offers the possibility of lower cost shipboard terminals for position determination. In 1973 these techniques were further tested for NASA by GE using ATS-5 at L-band frequencies, using ground-based terminals. Results obtained were similar to those obtained at VHF; that is, they indicate that it is technically feasible to obtain position accuracy of approximately 0.1 nautical mile with tone-code ranging from geosynchronous satellites.

Tests run concurrently by MARAD in 1973 with a pseudo-random code indicate that position-fixing with this technique is also technically feasible. NASA has conducted other experiments using side-tone ranging, and this technique also can provide the desired results. Trade-off of power, equipment costs, processing required, and necessary radio bandwidth is essential to determine the optimum system for any particular set of circumstances. MARAD is currently completing a study that looks at some of these aspects. The ATS-6 L-band experiments to be conducted during June 1974 to May 1975 will continue to acquire data on position determination through two satellite ranging techniques. Ships of the USCG and ESRO will use side-tone ranging techniques developed by NASA in a system called the Position Location and Communication Experiment (PLACE). MARAD will use the pseudo-random code system used in 1973 on two U.S. merchant ships. Data on both accuracy and radio-propagation anomaly will be obtained. Experiments in monitoring ship traffic using ship positions established with the help of space systems are an element of the MARAD tests. Experiments will also be done in use of accurate ship locations to improve ship utilization and to improve ship routing. The USCG will conduct a search and rescue demonstration and evaluate the impact of satellites on merchant vessel safety. In the search and rescue demonstration, ATS-6 will be used with aircraft of the Federal Aviation Administration and ESRO and an L-band buoy provided by ESRO. The limited time for maritime experiments on ATS-6, however, will restrict these experiments to short demonstration periods.

The 1967-68 study report of the Panel on Navigation and Traffic Control discusses "Operational and Management Communications" but in a rather limited way, since the subject was outside the Panel's assigned tasks. However, major interest and need have developed for reliable communication services that can be used 24 hours a day to improve the management and operation of ships and other marine activities. Major efforts have been expended in the past six years to conduct experiments, generate interest on the part of the commercial shipping industry, and stimulate the venture capital needed to launch a private commercial service.

RECOMMENDATIONS NOT FULLY IMPLEMENTED OR NO LONGER VALID

Response to the recommendations of the Panel on Oceanography has not been entirely satisfactory. The statement from the 1967-68 study report that "satellite technology has not as yet had significant impact on oceanography"* is still true. This does not imply that progress is entirely lacking. Much has been done to develop new instruments and to improve existing ones, but this work has not progressed to an operational system. Aircraft were used full time to develop these instruments, but at present, no buoy or ship program is specifically operated to provide the sea truth data needed to calibrate spacecraft instruments and to aid in interpretation of signals from these instruments. All too often forecasted winds, nonreal-time wave measurements, and a few laser profiles of waves, rather than comprehensive data from *in situ* instruments, have been used for calibration of the space sensors. The help and advice of fishery biologists in the development of new systems have been lacking and a recommended vigorous program to assess and develop a chlorophyll spectroscopy system suitable for satellite use has produced only a weak effort.

Recommendations that are no longer valid are concerned mainly with refinement of user needs; for example, conventional photography from space (replaced by scanners operating in the visual wavelengths) and laser altimeters (replaced by radar) are no longer needed. The requirement for ground resolution has increased from 10 to 1 km for many oceanic measurements (for example, to detect small and intense oceanic features of importance to fisheries and to see through holes in clouds) and to 100 m for small-scale phenomena such as coastal features, ice, and pollutants. The accuracy needed in chlorophyll measurements is now considered to be within a factor of 2 between 0.1 and 20 mg/m^3 and the emphasis has shifted from the chlorophyll response at 0.67 μm to the blue portion of the spectrum. Temporal coverage of coastal dynamics needs to be tailored to the time scale of the local situation, including tidal effects. Observations on the order of every half hour over regions of 100 to 200 km with resolutions of 100 m or better are required. These data can come from observation with instruments of high spectral resolution in the visible part of the spectrum.

The 1969 report of the Panel on Navigation and Traffic Control includes a recommendation for R&D on improved angle-measurement techniques. Little additional work has been done and current research has emphasized ranging techniques. In addition, the report recommends that a national policy statement and plan for navigation be established, and that international negotiation and arrangements necessary to implement the plan be initiated.

The report concludes that a satellite navigation and traffic control system will result in such benefits as (1) reduction in ship collisions and strandings, (2) savings in operating costs of shipping lines, (3) increased efficiency in commercial shipping, and (4) faster search and rescue at sea. These conclusions are considered to remain valid, but at this time (1974), an economical method of meeting these goals has not been achieved. Questions of who will provide the system and how it will be funded remain unsettled. The user community has yet to take a strong position on its needs and probably will not until there is a clear understanding about future charges to users. In the meantime, the federal government is continuing to fund and expand various position determination systems such as LORAN, OMEGA, TRANSIT, and a Department of Defense (DOD) satellite-based system proposed for the 1980's, referred to as the

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**Report of the Panel on Oceanography*, (1969), p. 83.

Global Positioning System. Although TRANSIT (properly referred to as the Navy Navigation Satellite System) has been made available to civilian users, it has not been taken into consideration to any significent extent in the overall planning of navigation systems. It is reasonable to assume that the proposed Global Positioning System will permit position determination to a precision exceeding the requirements of the maritime community, but it is not clear whether the civil community will be permitted to use the system, and if so, what precision will be provided for civil users. No response has been made to the users' need for international agreement on a uniform system of radio navigation aids. Bilateral agreements have, however, been signed between the U.S. and six foreign countries for implementation of a worldwide OMEGA system.

In addition to specific recommendations, the 1967-68 study proposed that a developmental system be designed and tested for confluence-area and enroute navigation for ships. Such a system is especially needed in outer confluence areas not served by land-based radar. There has been little or no evidence of interest since the 1968 study in the use of land-based radar, except for some harbors where it has been adopted for vessel traffic monitoring systems. Studies of traffic systems for confluence areas have been made by the USCG; however, the techniques studied have not included satellite-based systems. A study by MARAD in 1973 examined traffic advisory systems and provided some preliminary cost-benefit data.

MARAD has made limited studies relating to integrated navigation and communication systems, including cost-benefits of such systems. The experimental demonstration of an integrated system, referred to earlier (pp. 4-5) in this report, did not reach final conclusions nor fully validate projected benefits of an integrated system. A more recent experiment, from July 1973 to February 1974, by the EXXON Corporation and the General Electric Company provided additional experience, from which it was concluded that both position determination and improved communications could bring significant benefits.*

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*LaRosa, R. M.; Furick, J. W.; King, D. W.: Anderson, R. E; and Hoffman, H. E. *Experimental Evaluation of Satellite Communications and Position Fixing for Maritime Users*. Joint Final Report, EXXON Corporation and General Electric Company, June 1974.

CURRENT NEEDS AND POTENTIAL USERS

Early in its study, the Panel on Marine and Maritime Uses attempted to determine current needs in the three broad areas being considered (monitoring, position determination, and communications), and to identify potential users of satellite data. Much overlap exists since throughout the whole marine community, each function is an end in itself and at the same time is interrelated with and contributes to the other functions.

MONITORING

Monitoring requirements for a large portion of the marine community have been well expressed by NOAA* and the USCG.** Further, within the NASA Earth and Ocean Physics Applications Program, a User Working Group has defined data needs on physical oceanographic processes, as an imput to planning of a satellite called SEASAT. Current needs in monitoring are briefly summarized and include:

> Improved data on and forecasts of physical and biological processes within the marine environment, including winds, wave spectra, currents, ice, temperature, salinity, biological activity and productivity, and coastal dynamics such as near-shore currents, sediment transport, erosion, shoaling, and wave diffraction.
>
> Improved monitoring of maritime activities, including merchange vessel operations, drilling and mining, and offshore dumping. Detection pollution from oil, sewage, sludge, industrial waste, and thermal outflows will be of particular interest in maintaining the quality and productivity of coastal waters.

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*Apel, John R. and Sherman, John W., III. *Monitoring the Seas From Space: NOAA's Requirements for Oceanographic Satellite Data.* NOAA Report AOML-LORS 6.73.1. June 1973.

**Mueller, E. J. and William, C. *Applications of Satellite Telecommunications Techniques to Coast Guard Missions.* Westinghouse Electric Company, November 1974.

The ability to monitor precisely the location of offshore structures and anchored and free-floating buoys, to support future commercial and scientific programs.

In general, areas requiring environmental monitoring may be broadly grouped into three geographic regions: estuarine and coastal, including the Great Lakes; open ocean areas with major current systems; and open oceans. The polar regions can be regarded as a fourth general area, but the requirements are quite similar to those for the coastal regions. Of the ocean regions, the U.S. territorial waters and proposed coastal economic zone are the most important to the U.S.

POSITION DETERMINATION

There exist a number of ground-based position determination systems, including LORAN-A (being replaced by LORAN-C), DECCA, and OMEGA. None of the ground-based systems provides global coverage. The Navy satellite navigation system (TRANSIT), available for civil use, provides global coverage but its accuracy is limited to about one-half mile and the procedure for using it is complicated and requires costly shipboard equipment.

The present proliferation of terrestrial position determination systems results in a dissipation of public and private funds, necessitates carrying aboard ships and aircraft different devices for navigating in various parts of the world, and wastes valuable segments of the already over-crowded electromagnetic frequency spectrum. The substantial growth in air traffic and increases in ship size and speed during the 1960's and the 1970's have been accommodated by a complex of navigational aids, with little coordination on a national or an international scale among the various types of user (air and marine, military and civil). The last international meeting on marine aids to navigation was held in 1947. The Panel on Marine and Maritime Uses foresees a need to replace existing regional systems with a unified and continuously available position determination system of sufficient accuracy (200 m) for maritime navigation in the high seas and in confluence regions. As a goal, such a system should be comparable with or less costly to operate than the present aggregate of systems and the associated mobile receiving equipment must be economical for the user to lease or own. Such a position determination system providing coverage between about 75° N or 75° S latitude can also be of benefit for ship movement advisory services, for maritime traffic control, and for users other than in maritime shipping.

The Panel sees a further need for this unified global position determination system to become integrated with a communications system of comparable scope. Several methods of achieving such integration are being experimentally evaluated. Preliminary analyses indicate, at least from the viewpoint of the user, an integrated communications and navigation system can best provide the services that will permit optimum ship management. Whether it will be more cost-effective to provide position determination and communication in one satellite or in a combination of satellites needs further study.

The DOT, considering the views of the Radio Technical Commission for Aeronautics (RTCA), the Radio Technical Commission for Marine Services (RTCM), and various other transportation users, has issued a National Plan for Navigation.* An accompanying letter of promulgation states that the Plan is the official source of navigation policy and plans for the Department. The purpose of the Plan is to provide for the orderly and efficient development, implementation, and operation of aids to navigation responsive to both current and future needs of civil air and maritime interests of the U.S. The Plan also acknowledges the needs of military users of airspace and coastal waters. However, the Panel concludes that the current Plan does not adequately take into account the potential benefits that can accrue from the use of space techniques. Little planning or experimentation is evident in the Plan to indicate that the need for an integrated system (that is, integrated from the user's viewpoint) of communications and position determination is being adequately addressed. The Panel believes that a forum for the introduction of new needs does not exist. The Panel views such technical entities as RTCM as useful but not adequate in themselves. The DOT is urged to establish a more effective means of determining user needs, including sponsorship of user conferences, experiments, and demonstration projects. Other federal agencies responsible for promotion of U.S. merchant shipping have initiated programs to explore available techniques and evaluate the benefits. A combined effort is considered essential.

A separate plan for military navigation services is maintained by DOD. It is significant that nearly all radio navigation systems for position determination employed around the world by the U.S. have been developed initially by DOD to satisfy military requirements. The civilian user of military position determination systems does not have an opportunity to adequately voice his needs. It is primarily in the planning and implementation of DOD systems with future civil availability where the user is least heard.

COMMUNICATIONS

The Panel considers that a need exists for continuously available and highly reliable maritime mobile communications. The Panel has identified a variety of needs for which space applications may be useful. These include the dissemination of service announcements, such as time signals; weather, wave, and ice bulletins and forecasts; the interchange of voice, teleprinter, data and facsimile services to manage better the operation of ships and offshore facilities; and the timely reception of ship movement reports and distress transmissions which contribute to a more rapid and efficient conduct of search and rescue operations.

Within the past three years, several factors have stimulated industry interest in communications improvement. Included are (1) discussions of U.S. positions regarding current international planning for maritime satellite communication services, (2) satellite communication experiments on U.S. merchant ships, (3) increasing capital cost of new ships, and (4) escalation of fuel costs with a resulting need for better at-sea control and management. Modern rapid communication services are now essential for the management of shipping.

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*Department of Transportation, *National Plan for Navigation*, 2nd revision. Washington, D.C., April 28, 1972.

Better means of expressing needs of the maritime user must be developed. To date, the ocean shipping community has expressed user views. Other commercial marine users such as fishing, exploration, scientific, and other offshore operators have yet to express their needs for maritime satellite communication services. The Panel has attempted to foresee the requirements of these users and to factor them into its recommendations. The Panel has found that much documentation of needs exists in the area of monitoring but that there has been little expression of user needs for position determination. The Panel has attempted to foresee at least to the 1990's any significant changes in user needs and its views are based both on the experience of this Panel and on interchange with other panels of the 1974 summer study. Maritime trade organizations have and should continue to voice the needs of commercial ocean shipping. Providers of commercial satellites can be expected to identify for users potential and profitable applications, both current and future. Government research programs such as the MARAD commercial fleet management program, environmental science and forecast services by NOAA, and merchant vessel safety programs of the USCG also will stimulate new uses of improved communications.

Current needs in navigation and communications are briefly summarized as:

A unified and continuously available global navigation system of sufficient accuracy to replace existing regional, high seas, and confluence area systems

Integration of position determination and communications systems

Reliable and rapid communication to better manage shipping and offshore operations through interchange of data and messages

Improved dissemination of time signals and service announcements such as weather, wave, and ice information.

Improved alerting and locating of ships and persons in distress as an aid to search and rescue.

While the potential users of monitoring, position determination, and communications facilities include federal, state, and local governmental agencies with maritime concerns (including law enforcement), the majority of users will be in the private sector, and include ship operators and management, naval architects, operators of offshore platforms and other offshore industries (such as oil exploration and production), fishermen, oceanographers and ocean engineers, and those engaged in search and rescue, recreation, coastal industries, and the operation of special ships (such as for cable laying and mining).

POTENTIAL BENEFITS FROM SPACE APPLICATIONS

The Panel visualizes potential benefits within the three broad areas considered: monitoring, navigation, and communications. In the whole subject of marine resources, these broad areas are overlapping and interrelated. Specific benefits therefore are not categorized but are seen to be valuable for many users throughout the marine community. For example, it should be noted that the remote sensors which must be developed for monitoring are only a part of the entire system necessary to achieve full benefits. Not only is it necessary to develop the technology, but also involvement in and acceptance of the new technology by the user community are required. These ideas are illustrated by the examples of potential benefits in areas outlined below.

COASTAL CIRCULATION

Coastal circulation is an important feature that threads through all coastal-related activities. It is important for (1) in fisheries, where larvae are moved from the spawning grounds through the prevailing current system to other regions where they either grow or perish, (2) water quality, which is subject to change at any point as a function of the tidal system and prevailing currents, and (3) protection of life and property, where the focusing of wave energy in the coastal region is gradually altered both by the methodical action of daily currents and where the dramatic effects of storms change the bathymetry and the shape of the coastline.

To describe coastal circulation using space techniques, both natural identifiers of water masses and artificial means may be used. The prime natural water-mass identifiers observable at a distance are sea surface temperature, salinity, suspended sediments, and suspended chlorophyll. Further, each is needed on a quantitative basis by the appropriate marine user community, so that multiple benefits are found in remotely observing and quantifying these parameters. Artificial means are primarily the injection of slowly released dyes from sources anchored near the surface and the use of free-drifting buoys which may be tracked by either satellites or shore-based radar, the latter being more appropriate where ocean current systems are highly influenced by tides.

Coastal circulation can be effectively described only by coupling tidal phenomena to the prevailing current system. In many coastal areas, tidal current is normally the strongest current system. Surface wind fields can alter surface circulation and during storms can dominate the circulation from the surface to the bottom of the sea.

The impact of these conditions on defining coastal dynamics makes it necessary to observe circulation on a temporal scale appropriate to the dynamics. Hence, tidal systems require repeated coverage every 20 to 30 minutes during flood, slack, and ebb. The cost of equipment and its emplacement would be quite large if the density of coverage necessary to define the details of coastal circulation were accomplished entirely by *in situ* means. For this reason, a combination of *in situ* and remote sensing techniques is needed. The ability of remote sensors with appropriate temporal coverage to provide synoptic circulation details brings significant benefits to the coastal disciplines.

ENVIRONMENTAL FORECASTING

Because the total ocean area of the earth's surface is large compared to the land area and because the oceans and the atmosphere interact in an important and complex way, much of the world's weather is strongly influenced by the waters and ice that comprise the oceans. The combination of surface measurements and satellite meteorological and oceanographic data will significantly assist in achieving the goal of meaningful one- to two-week forecasts. Accurate five-day forecasts will immediately improve U.S. shipping operations. These five-day forecasts should reduce by an estimated 5 to 10 percent the present global shipping cargo and damage losses of about $500 million per year and should permit reductions in trans-oceanic transit time up to 10 percent (in the Atlantic, 12 to 24 hours; in the Pacific, 12 to 60 hours).

HAZARD DETECTION

It is difficult to predict consistently, 24 hours in advance and within 200 km, the landfall of a major weather disturbance (for example, a tropical cyclone) and the resultant storm surge. As the number of people living along the coasts (where about 80 percent of the U.S. population now resides) and as the offshore facilities contemplated for coastal regions increase, the potential for loss of life and property increases proportionately. In the world's low-lying areas -- for example, in the region of the U.S. along the Gulf of Mexico, where more than 30 million people dwell -- early warning of severe hurricanes is absolutely essential to permit evacuation of the population. Observations of sea-air interactions, sea surface temperature, wind, and waves, as well as an increased understanding of the storm-surge process, will permit a large step forward in providing the required warning.

Compilation of data on wave spectra, focusing of wave energy, and storm-induced longshore currents is critically needed to improve ship and ocean structure design.

The location of some 2000 to 3000 shoals on world hydrographic charts is uncertain. Such shoals, although shown on navigation charts, may not even exist, and they currently require avoidance by as much as 50 km for the conservative ship navigator. The existence and precise location of the shoals can be determined using high spatial resolution instruments operating in both the visible and the microwave regions of the electromagnetic spectrum.

FISHERIES

From 1959 to 1969, imports of fishery products accounted for 19 percent of the total deficit in the U.S. balance of payments. In the late 1950's, the annual deficit was on the order of several hundred million dollars. Currently about 70 percent of fishery products used in the U.S. are imported, and the deficit is about $1.5 billion per year. An increase in the productivity and protection of fisheries in our own coastal waters is needed to reduce U.S. dependency on other nations. Remote sensing techniques can be of benefit in (1) understanding fisheries-related biology to conserve fish stock and establish maximum sustainable yields for the stocks, (2) enforcing international and other conventions and agreements related to fisheries, and (3) forecasting environmental conditions best suited for specific species of fish to determine the most likely location of schools.

It is necessary not only to improve U.S. coastal fisheries, but also to inventory fish stocks on a global basis. The total world-wide needs for protein must be met by the combined supply from the sea and from the land. The strain on the U.S. supply of soybeans that occurred when the anchovies off the coast of Peru disappeared attests to the importance of the sea's contribution. Antarctic krill may well be an untapped protein source of the same magnitude. Their availability is not yet well established but they school together at the surface during certain portions of their lifetime in dense numbers and over areas of hundreds of square kilometers. Analysis of satellite data in conjunction with surface studies may be the most economical method for census of this stock.

ICE SURVEILLANCE

It has been estimated that at any given time approximately 10 percent of the ocean surface in the Arctic region is open water. Thus, the concept that the Arctic is covered by an insulating blanket of ice is in error. This quantity of open water significantly affects meteorological and climatological conditions. The heat flow through the water-air interface is between 2 and 3 orders of magnitude greater than the heat flow through the water-ice-air interface. The dynamics and forecasting of ice strain in terms of ice type, leads, and polynyas (ice-free passages) are thus important not only to shipping but also to long-term weather forecasts which are significantly affected by the location of major points of energy. To achieve these ends, the Panel believes that the Polar Experiment (POLEX), as a part of the Global Atmospheric Research Program (GARP), should be supported as a major program by NASA during the next decade. The benefits will at first be scientific, that is, (1) the synoptic view of ice conditions, and (2) the availability of surface truth for instrument calibration and validation. An intangible benefit will be the provision of an area for international cooperation. Economic benefits can be established only through improved weather forecasting both for ocean and continental environments.

In addition to effecting weather and climate, ice presents a hazard to marine transportation in various parts of the continental U.S. and in Alaska. The Great Lakes, the U.S. central river system, and New England are becoming more and more important to the transportation of commodities. Nearly all iron ore which moves in the Great Lakes region is carried by ship. Significant amounts of wheat, oil products, coal, and finished goods also move across the region by ship. Most vessels operating in the U.S. are not designed to operate unaided through ice-covered waters and ice-breaking service is provided, usually by the federal government (U.S. Coast Guard). Therefore, capabilities to determine ice coverage, clear water passages, pressure ridges, and ice thickness are important to success in extending the navigation season. An interim report* on the extension of the St. Lawrence and Great Lakes navigation season beyond the December 15 closing date shows the following estimated economic gains:

	Gain in Millions of Dollars		
Navigation season extended to	Jan. 31	Feb. 28	Year round
By 1975	40	58	68
By 1985	85	123	145

These gross estimates are based on a number of factors including improved ice surveillance, better data analysis and better prediction, all-season aids to navigation, and increased icebreaking activity. No attempt has been made to assess the individual economic benefit of each of these contributing elements. It is not possible at this point, therefore, to estimate what portion of the potential benefit would be derived from improved ice surveillance and forecasting.

Arctic and Antarctic icebreaking has historically been conducted in support of scientific investigations and, to a limited degree, in military operations. Recent discovery of oil deposits on the Alaskan north slope, coupled with the political and economic ramifications of a dependency on Middle East oil supplies, has spurred activity in the far north. Scientific and geological surveys, commercial oil drilling, ocean transport, and supporting icebreaking requirements in high latitudes will place increasing emphasis on all-weather sensing and predicting of ice extent, polynyas, ice thickness, pressure ridges, and the discrimination of new ice from multi-year ice. The benefits of more complete data gathering and ice forecasting should be

More efficient icebreaking operations

Reduced damage to vessels and structures

*U.S. Army Corps of Engineers. *Great Lakes Navigation Season Extension*. Winter Navigation Board, Special Status Reports, U.S. Army Corps of Engineers, July 1974.

Increased safety of personnel

More economical or otherwise advantageous vessel transport of petroleum and other resources.

POLLUTION

Oil pollution constitutes a major threat to U.S. water resources, marine life, waterfront property value, and the recreational industry. The frequency of occurrence of oil pollution incidents are generally agreed to be a function of the number of transfer operations between vessels and shore facilities, volume of oil transferred, number and length of vessel passages within U.S. waters, and number of offshore oil wells.

The size of the area to be monitored is significant. It includes thousands of miles of rivers, lakes, harbors, and coastal waters. Remote sensing techniques which enhance the ability to observe pollutant discharge will materially assist in the enforcement of applicable laws and will tend to ameliorate environmental damage through more rapid response and cleanup.

The USCG has observed marked decreases -- up to 25 percent -- in the number of oil spills when continued surveillance of critical areas has been employed.* Although much of this decrease can be attributed to increased attention to handling and transfer methods, the fact that better and more complete surveillance is being conducted tends to dissuade the intentional polluter. The cost of daily observation of certain harbors and waterways with existing vessels and aircraft by the USCG is estimated to be between $2 million and $4 million. The cost may exceed $18 million if a dedicated system for surveillance of pollution is extended to all major U.S. continental lakes and coastal waters. At present, high-resolution radar, imaging microwave radiometers, and multispectral low-light-level television are being installed on aircraft for surveillance in low-altitude flights. It is estimated that yearly costs could be decreased by about one-third or one-half through the use of sensor systems which can detect surface oil sheens of 1,000 m^2 or greater from aircraft flying at high altitude (and thus having increased swath widths).

Assessing long-term environmental changes is another benefit which can accrue from daily wide-area monitoring of oil spillage and waste dumping. There is a need to observe, over a period of time, pollutant levels and their subsequent impact on and toleration by the marine environment. Assessing the ability of ocean and coastal processes to dissipate hazardous polluting and noxious substances is considered necessary. Until such time as these and other processes are better understood, it will be impossible to estimate the quantity of waste which can be safely disposed of in the oceans and to determine the long-term economic impact of oil spills and waste dumping.

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*Gerhard, Glen: *A Study of the Cost Effectiveness of Remote Sensing Systems for Ocean Slick Detection and Classification*. National Sea Grant Program, U.S. Coast Guard, Washington, D.C., 1972.

ENDANGERED MARINE LIFE

The Marine Mammal Act of 1972 (P.L. 92-522) focuses on the need to assess stocks of specific species of marine life in order to assure their continued existence as well as to obtain the ultimate goals of restoring and maintaining a viable commerce with certain of these species. The prime current need is to conduct a census of many mammals including, for example, sea otters, gray and bowhead whales, walrus, and seals. Three techniques appear appropriate for the purpose: (1) tracking of animals by surface, aircraft, or spacecraft observations, to determine the habits of the creatures, in particular, the time in and out of the water, (2) determining areal extent of the herds and numbers of animals in the herds by overflights by aircraft, and (3) where appropriate, tracking ice fields by satellite to assess and forecast locations of ice where these animals are most likely to be found and thus to reduce aircraft search time. Beyond those arising from the preservation and conservation of these marine animals, benefits are difficult to establish.

POSITION DETERMINATION

Civil maritime navigation (of which an important element is position determination) has traditionally been divided into three categories: the high seas, the coastal confluence regions, the harbor and harbor-entrance zones. The high seas are defined as areas remote from land masses where visual references to land or other fixed or floating aids are not possible. The coastal confluence region includes those waters contiguous to major land masses or island groups where ships tend to converge toward harbors and where significant traffic exists in patterns essentially parallel to the coastlines. The harbors and harbor-entrance zones include those waters inside the mouths of bays and rivers.

The primary benefit to shipping of a position determination system for the high seas is the capability for a ship to follow closely a minimum-time or least-energy transit route across open ocean areas between more complex coastal zones. Such a system provides a means whereby a vessel may fix its position in the absence of visual or other short-range references. It should be capable of providing position fixing adequate to enable the mariner to avoid charted obstructions such as reefs, remote island groups, and coasts where, for whatever reason, navigational aids do not exist. Oceanographic activities require position fixing of even higher accuracy to correlate by position various measured data. Persons in distress will benefit if their position is known by search and rescue authorities.

In the coastal confluence region, the ability to navigate in proximity to land masses during periods of reduced visibility is a general benefit to shipping that results from a position determination system. Higher density of ship traffic in these regions and a resulting increase in hazard for collision or stranding imposes greater requirements for accuracy than on the open sea. The system should provide position fixing capability having an accuracy of approximately 200 meters. This accuracy is necessary to support anti-collision procedures such as maintaining traffic separation. Some commercial fishermen have more stringent requirements, such as navigating parallel tracks or operating as closely as possible to known bottom obstructions without hazard to their equipment. Agencies responsible for marking navigation channels and tracking oceanographic buoys have expressed a desire for precise determination of the positions of anchored and free-floating buoys and structures. The accuracy required is about 30 to 50 meters. Such capability does not currently exist. Vessels, aircraft, or possibly shore-based radar therefore are required periodically to locate these buoys and to determine their precise movements. Checks on the position of anchored buoys is necessary to determine if they have broken loose or have shifted position.

An important feature of a position fixing system is its repeatability; that is, the ability to return to a position previously fixed, whether that position corresponds to a true position or not. A system with high repeatability can be used to track buoys or locate positions (fishing areas, for example) to which it is desired to return. Today, many fishermen locate fishing grounds not by an extact geographical position, but by using LORAN-A or LORAN-C time-difference coordinates, which have high repeatability. OMEGA and TRANSIT, on the other hand, have lower repeatability because they require factoring in time-variant corrections to establish a position. Any future space-based position determination concept should take into consideration the advantages of repeatability.

The Panel has considered alternative approaches which can provide position determination service on a worldwide basis. These include the present OMEGA and TRANSIT systems, the proposed DOD Global Positioning System, and the postulated satellite system of integrated communications and navigation.

The Panel recognizes that a comparison of the cost of existing position determination systems with that of proposed satellite-based systems is desirable. Some cost data on operational systems are available but they are incomplete. Comparisons of systems with varying coverage and capability as well as with differing user equipment costs are too complex and difficult to be attempted within the time and resources available to the Panel. The Panel notes that recent cost studies of terrestrial hyperbolic systems for the coastal confluence area have been made by the USCG* and a general analysis of all position-determination systems has been undertaken by the Office of Telecommunications Policy.

COMMUNICATIONS

The Panel agrees that the marine community can derive many benefits from the development of high-quality communications and feels that these benefits can be extended to the U.S. inland waterway industry. A recent study of communications requirements within the inland waterway industry has been conducted by ARINC Research Corporation for MARAD** and delineates services that are needed. This study concluded that a satellite system to serve solely the inland-waterway industry was not economical and that in any event it could not be provided by the time it was needed (mid-1970's). Nevertheless, as other domestic uses of satellite communications grow, there may come a time when satellite communication

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*Polhemus Navigation Sciences, Inc., *Radio Aids to Navigation for the U.S. Coastal Confluence Region*. DOT-CG-22166-A, July 1972.

**ARINC Research Corporation (A Report for the Maritime Administration). *Inland Water Communication Study*. National Technical Information Service, Springfield, Virginia, May 1974.

services become competitive with terrestrial services for the inland waterway industry.

The Panel believes that the marine community will derive numerous benefits from rapid and reliable communications, particularly to vessels on the high seas. Such systems can contribute to

1. Active management of ship operations including inventory control; optimum international and national purchasing; maintenance, repair, and diagnosis of shipboard fault conditions; scheduling of in-port services; prediction of shipyard overhaul; optimum cargo loading; personnel management; and accounting

2. Improved utilization of capital assets

3. Reduced fuel cost and reduced ship and cargo damage

4. Enhanced safety of personnel and property

5. Possibility of reduced insurance premiums in the future through decreased losses

6. Reduced requirement for large onboard computers to perform operational or scientific data analyses which can be more economically performed ashore

7. Medical, educational, and entertainment services to ships.

Satellites offer the ability to realize these improvements with high circuit reliability. At the same time, satellites offer wider bandwidths than are available for terrestrial circuits, and thus permit highspeed data transmission and other services not available from terrestrial stations. In addition, the use of satellite communications may reduce somewhat the present congestion on high frequency radio channels.

ECONOMIC ESTIMATES OF POTENTIAL BENEFITS

It is extremely difficult to assess accurately the economics of the maritime industry. Among the variables that must be taken into account are vessel size, trade route, and class (for example, tanker, freighter, ore ship, etc.). In addition, freight rates for marine bulk cargo depend on a number of variables and fluctuate daily.

One aspect of marine economics is touched on in a recent report regarding U.S. energy posture and forecasted needs prepared by the National Petroleum Council.* The report indicates that by 1985, 50 percent of U.S. petroleum requirements may be imported. If this were the case, between 10 million and 11 million

*_Law of the Sea_, National Petroleum Council, May 1973.

barrels of oil a day would be transported by ship from the Middle East. To fulfill this requirement, the U.S. would need to be served by 400 vessels each having a capacity of 250 thousand deadweight tons. Using the average freight rate of $10.59 per ton which prevailed as of January 1, 1974,* the following factors apply in calculating what the annual freight cost would be by 1985 if 50 percent of U.S. petroleum requirements are imported:

Annual cost per vessel	$12.6 million
Number of vessels	400
Total freight cost per year by 1985	$ 5.04 billion

Due to the many variables in operating cost, such as the price of bunker fuel and fluctuating freight rates, even what might appear to be insignificant savings in time, distance, or fuel actually accrue to important amounts. For example, on December 31, 1972, the daily cost of operating a tanker of 250 thousand ton deadweight capacity was $22,000. On January 1, 1974, this cost had escalated to $36,500. The difference resulted principally from increases in the cost of bunker fuel.

A major U.S. dry-cargo company estimates that improved navigation capability will result in a distance saving of about 80 kilometers on a trans-Atlantic crossing from New York to Gibralter. Computed fuel savings, using a fuel cost of $10.80 per barrel and a consumption rate of about 2 barrels per mile, amounts to approximately $2,160 per round trip. Projecting these amounts to 570 U.S. ocean-going ships and assuming six round trips per year, yields potential annual savings on fuel alone of the order of $7.4 million. On an international scale, more than 40,000 ocean-going vessels are involved and the potential savings are enormous.

In the past five years, world-scale freight rates have fluctuated by as much as a factor of two to three times. The economic impact on marine transportation has been devastating. Any potential saving of ship operating time therefore is of tremendous significance. Improved weather routing, which in some instances provides time savings up to 10 percent, would offer significant economic benefits. For example, a freighter of 250,000 tons deadweight capacity requires 60 days of steaming for a round trip from Portland, Maine, to Mina Al Ahmadi on the Persian Gulf. A 10 percent saving (6 days) at $36,543 per day provides a possible savings of about $219,260. While savings of this magnitude will not be realized for all vessels all of the time, improved weather forecasting and ship routing will nevertheless significantly aid commerce, particularly on trans-Atlantic and trans-Pacific passages.

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*Since the summer study, the freight rate has decreased somewhat.

CAPABILITIES REQUIRED IN MARINE APPLICATIONS

MONITORING

Open-ocean physical oceanographic requirements appear to the Panel to be well-addressed by NOAA and the SEASAT User Working Group. The instrumentation planned for SEASAT-A, which is expected to lead to operational systems for the oceanographic community, includes an altimeter, scatterometer, multifrequency and polarization microwave radiometer, infrared imager, and high-spatial-resolution radar imager. This ensemble of instruments will permit the collection of data on wind, wave spectra and their refractions, currents, and the shape of the geoid, and will satisfy the research and development required to achieve many of the benefits envisioned in physical oceanogmaphy. Additional information can be derived by cross-analysis of the measurements from this collection of instruments. The Panel strongly endorses the instrumentation plan.

The Panel believes that the observation of biological phenomena necessary to satisfy oceanic requirements is less well developed. In part this is due to a lack of stress on the importance of monitoring ocean chlorophyll. Photosynthesis in the ocean fixes as much carbon in the form of glucose as all terrestrial forms of photosynthesis combined, including both controlled and uncontrolled growth. Chlorophyll-a is primarily responsible for the photosynthesis process in the ocean as well as on land. The importance of monitoring ocean chlorophyll-a is multifold: (1) it is a means of water-mass identification, (2) it is the first form of food in the sea life cycle and its availability and distribution may be used to locate animals such as fishes, that are higher up in the food chain, (3) the rate of production of chlorophyll, or productivity, can be used to assess the total yield of food potentially available from the sea and to determine the global balance of oxygen and carbon dioxide when it is coupled with other ocean variables such as temperature and terrestrial observations, and (4) the quality of the water can be determined in terms of chlorophyll concentration since high concentrations, particularly at the surface, are typically regarded as an indication of pollution or an unhealthy situation, whereas low concentration may be quite normal in terms of seasonal effects and location or may represent the result of some form of pollution which has killed the previously available chlorophyll.

Two primary factors are believed by the Panel to be responsible for the failure to advance the status of biological oceanography in the space program. First, the development of instrumentation for both aircraft and spacecraft has been slow and only limited data from aircraft exist; consequently, the instrumentation proposed for satellite observation (NIMBUS-G) is at best marginal.

It should be upgraded to include a channel in the orange part of the spectrum to satisfy certain requirements set up by NASA.* Secondly, the biological-oceanography community is not sufficiently involved in the NIMBUS-G program and only to a limited extent in the planned research and development on a Scanning Imaging Spectroradiometer (SIS) to be carried at high altitudes by an airplane. The Panel regards biological remote sensing as a high priority item which should be addressed by a NASA program and which should be explored fully by the biological-oceanography community through experimentation.

Only in the area of data collection systems has the use of satellite systems in monitoring advanced to the operational phase. The Synchronous Meteorological Satellite (SMS) or the Geostationary Operational Environmental Satellite (GOES) has the capacity to handle 10,000 or more data collection platforms in either an interrogated or self-timed mode of operation. This technology, as well as associated ground systems for terrestrial applications, is currently operational. A study is underway to insure compatibility between the Earth Resources Technology Satellite-1 (ERTS-1**) data collection system and the SMS or GOES data collection system. Polar-region coverage will be insured by the TIROS-N Data Collection Platform (DCP). The application of the SMS or GOES system to marine needs is hindered primarily by additional costs of using the system in the harsh ocean environment. In the developmental phase, techniques for position location of drifting buoys using a data collection system have shown that accuracies of 1 to 2 kilometers can be achieved. It appears that in the use of data collection systems for marine activities, emphasis should now be placed on lowering the cost of *in situ* instruments and the associated surface operations. Perhaps this can best be brought about by creating a broader awareness of what can be accomplished through making full use of the capabilities of existing spacecraft.

Research based on Skylab altimeter data has advanced measurement of the geoid to the developmental phase. Although the altimeter on SEASAT-A is only a research instrument, it appears suitable for determining the level and the slope of the ocean surface which in turn cause deflections of the apparent "vertical" from that through the center of the earth. These features of the ocean are thought to be the result of gravity anomalies. They are important to geodynamicists in understanding ocean dynamics and they have other effects such as on the accuracy of inertial navigation systems.

All other techniques for monitoring of other ocean variables from aircraft and satellites are in the research and development phase. Aircraft monitoring of certain limited areas can be made operational during the next 5 years to support monitoring of U.S. coastal environments just as aircraft are used for law enforcement in these regions. However, no plan yet exists for such an approach. A study is warranted to determine the requirements for an operational aircraft system to support multiple coastal needs and to decide how to implement and manage this program. Elements of a useful research and development program for instruments previously proposed should include:

**Advanced Scanners and Imaging Systems for Earth Observations*, NASA SP-33, 1973, Ch. 1.

**Since renamed LANDSAT.

Further development of instruments to measure wind, waves, and temperature over the ocean. Data from these instruments have immediate usefulness since they can be applied to fisheries, weather forecasting, and ship operations. Furthermore, users have facilities to process these data.

Calibration of instruments, including development, prototype, and operational models, against the best surface measurements available. Space instruments may be better in some respects than current conventional ones but this cannot be determined without valid measurements and calibrations.

Development of instruments that are capable of providing data necessary for improving fisheries and include better means of measuring biological productivity.

Improvement of models to forecast weather, wave conditions, and ice movement using data derived from these instruments. The weather-forecasting models should include the effects of oceanic winds and the surface layer of the ocean. Improved 5-day forecasts will have immediate benefits.

The Panel believes that the major problem in achieving real benefits from applying space systems to maritime monitoring activities is an institutional one. A lack of focus, both in the marine community and in NASA, does not permit the emphasis and management necessary to accomplish potential benefits. To date, marine monitoring has ridden on the successes of other space applications programs and has not been a program in its own right. Some requirements of marine monitoring are similar to those of both meteorology and earth resources but, where differences in spectral coverage and resolution have become an issue, decisions have not been made in favor of the marine community. Hence, it is the strong opinion of this Panel (1) that marine-monitoring interest should be focused in a single seat of authority in NASA and (2) that necessary coordination should be the responsibility of an interagency body such as the Interagency Committee for Marine Science and Engineering (ICMSE).

The Panel sees a necessity for the close involvement of users in

Specifying type, quality, and quantity of data needed to meet their goals

Evaluating instruments from the developmental phase through the operational system

Specifying data processing systems.

The eventual goal is to provide operational information to users. It is specifically noted by the Panel that while some federal agencies will be users, most of the users will be fishermen, ship operators, offshore petroleum interests, and the millions of ordinary citizens who use the seashore and coastal waters for recreation.

COMMUNICATION AND POSITION DETERMINATION

The Panel concludes that innovative development actions must be taken to determine optimum techniques for providing an integrated navigation and communications system of appropriate capability for ocean shipping. The Panel agrees that space systems can provide the economy and reliability necessary. Further study must be made to determine the most effective way to provide position-determination services at high latitudes which the Panel believes will be required in the early 1980's.

Full advantage of satellite communications systems should be taken to insure the availability of the integrated position determination and communications necessary for modern ship management. An additional but moderate research effort is required. Emphasis must be placed on feasibility-demonstration systems to provide evaluation in terms of availability and accuracy. Further information on costs can be developed as alternative methods are demonstrated. User evaluation can proceed concurrently. It may be expected that commercial shipping companies will modify their management techniques in order to exploit continuously available data on ship positions integrated with shipboard monitoring, on-board information processing, and automatic transmittal of status data to management and control systems ashore. Other users will be able to take advantage of the capabilities developed for commercial shipping and thus economically meet many of their needs.

Current planning for spacecraft systems is limited to or is tailored to the size and weight limits of current space transportation vehicles. The Panel considers that future systems should permit payloads without such limitations. In this way position determination capability can be combined with programs in other appropriate spacecraft at significant cost savings.

Tests now scheduled for ATS-6 (1974-75) will provide additional data on satellite-based ranging techniques. NASA involvement in its own tests, in those of other agencies (DOT, ESRO, and MARAD), and in a current NASA research program in position determination and traffic control should provide sufficient data to design an adequate demonstration project. A major problem in the implementation of such a position determination demonstration is the availability of adequate spacecraft for a sufficiently long period. Looking to the immediate future, MARAD has been reviewing alternatives within its joint program with NASA to develop the demonstration. Shipping companies have indicated preliminary interest in participation. To be effective, the program requires frequent and relatively long evaluation, probably during a significant portion of each day for 8 to 12 months. Current planning envisages integration of position determination with communications and now centers around the 1977-80 time frame. Spacecraft which may be used include MARISAT, ATS-6, or Aérosat.

As has been discussed, a major national re-evaluation of government-provided position determination services is required. Concurrently also, a forum for international discussions must be implemented, and this institutional matter may be the most difficult to achieve.

The Panel is of the opinion that several areas still require productive research and development in the field of communications. In order of relative importance these requirements include:

1. Less expensive spacecraft power generation to increase channel capacity and permit reduced message charges

2. Improved spacecraft antenna systems to reduce the size, complexity and cost of the shipboard equipment

3. Provision of economical service in the polar regions and relay of service over multiple-system segments

4. Adapting satellite capability to serve user needs, particularly in exploiting multiple-use satellites

5. More efficient (in terms of power and bandwidth) modulation techniques

6. Integrated shipboard sensor and transponder systems for remote collection and retransmission of environmental, structural, and machinery parameters

7. Propagation and multipath data for the maritime band (1535-1660 MHz)

8. Investigation of spectra suitable for future needs of satellite maritime mobile communications.

The Panel further concludes that future maritime operations will require high-latitude operations in both polar regions. Such operations will include commercial transport, research of polar areas, mineral and fuel production, structures highly related to marine operations, fishing, and acquisition and monitoring of ocean environmental data. Current satellite systems now being implemented will use geosynchronous orbits of low inclination. Analysis and experimental evaluation of techniques must be initiated to insure that such service will be efficiently integrated into the communications services provided for the polar areas by the current design system.

An operational maritime satellite communication system, MARISAT, will be available in mid-1975. Two geosynchronous satellites will provide coverage over most of the Atlantic and Pacific Oceans. ATS-6 will be used for communication experiments for a year starting in July 1974, with additional use planned in 1976. ESRO plans to launch an experimental maritime satellite (MAROTS) in 1977. The Panel concludes that emphasis should properly be placed on the extension and improvement of these systems and foresees larger satellites of greater capability for mobile uses. The near implementation of operational systems will stimulate new and innovative applications of space technology and will be a catalyst for users to seek advancement of this technology. The Panel considers that continued federal research efforts are essential to permit significant exploitation of space applications by users within the U.S. marine industries. Termination of research and demonstration programs at this time will cause current progress to be lost to these users and prevent use of the benefits obtained from past research funding.

CONCLUSIONS AND RECOMMENDATIONS

The Panel on Marine and Maritime Uses has examined the general area encompassed by its terms of reference and concludes that three broad functions should receive major attention. These are monitoring of the marine environment, position determination, and communications. As a part of the Panel's initial analysis, potential users who can apply satellite data systems to their needs are identified in each area. Much overlap exists since each function is an end in itself and at the same time is interrelated with and contributes to the other functions. Needs in each area are examined and defined. The Panel finds much documentation of needs in some areas (for example, in monitoring) and little user expression in others (for example, in position determination). An attempt was made to foresee at least to the 1990's any significant changes in user needs, relying both on the experience of this Panel and on interchange with other panels within the 1974 summer study.

MONITORING THE MARINE ENVIRONMENT

The Panel on Marine and Maritime Uses reached the following conclusions relating to the function of monitoring of the marine environment:

1. Man's increasing activity on and near the oceans and his continuing dependence on the sea as a source of protein leads to an increased need to monitor and forecast the natural environment and to manage maritime activities. Satellites can make an important and unique contribution by supplying the data on which forecasts and management depend.

2. The general goals outlined in the 1967-68 summer study are still appropriate to marine needs today, but operational requirements have been altered to some extent through subsequent studies within the marine community.

3. There has been good development of instrumentation for the measurement of physical parameters noted as significant in the 1967-68 study report.

4. Importance of the oceans as a source of protein is widely recognized, yet there has been little involvement of the biological and fisheries community in specifying what data are necessary to assess biological productivity and in determining the best means of obtaining these data.

5. Research and development of sensors has concentrated on hardware techniques. Continued comparison of specific data from these sensors with valid *in situ* measurements throughout the entire cycle of research and development has been inadequate.

6. An understanding of coastal circulation is necessary to help solve many near-shore problems such as pollution, sedimentation, and erosion. Remote sensing techniques are well suited to provide the required temporal and spatial coverage.

7. Many of the instruments used by the marine community for remote sensing have been designed primarily for other applications. Few instruments have been specifically tailored to marine needs.

8. Many of the difficulties stated herein are institutional in nature and acceptable solutions must be responsive to the needs of the marine community.

9. It is difficult to anticipate monetary benefits that can be derived from the application of aerospace techniques to global monitoring. Cargo and shipping losses are now around $500 million yearly. Improved weather and wave forecasts should reduce this amount by 5 to 10 percent. The balance of payments deficit attributed to importing of fish and fish products is now around $1.5 billion yearly. Improving U.S. fisheries will lessen dependence on foreign products and help to alleviate the deficit in balance of payments.

The Panel offers the following recommendations relating to the function of monitoring of the marine environment:

1. *Research and development should continue to address the basic recommendations of the Panel on Oceanography in the 1967-68 study.*

2. *Increased emphasis should be placed on the needs of biological oceanography and fisheries.*

3. *Increased attention must be paid to the 1967-68 study recommendation made by the Panels on Oceanography and Points-to-Point Communications that greater emphasis be placed on the collection and analysis of in situ and other relevant forms of sea truth, including information from buoys.*

4. *Stronger emphasis should be given to the application of remote sensors in the coastal environment, in particular, in circulation analyses, because immediate benefits are possible.*

5. *Care should be taken not to compromise marine requirements in sensors that are designed for multiple-discipline use.*

6. *A single seat of authority for marine interests should be established within the Office of Applications of NASA.*

7. *Either an existing body should be designated or a new one should be created to work with NASA to determine priorities, coordinate programs, and maintain requirements for the marine community. This body should include representatives from federal and state agencies and from commercial marine users. It should provide a forum for early, effective, and continuing voices in programs designed to use remote sensing in marine applications.*

NAVIGATION AND POSITION DETERMINATION

Conclusions closely related to navigation and position determination include the following:

1. The recommendations of the Panel on Navigation and Traffic Control in the 1967-68 study are valid and have not been implemented.

2. The proliferation of current operational position determination systems provides overlapping services, none of which is completely adequate. The result is wasteful to the operator and user and is wasteful of government funds and of the radio frequency spectra.

3. A number of experiments using several techniques for satellite maritime position determination have been completed and demonstrate basic feasibility.

4. A need exists for a unified and continuously available global position determination system of sufficient accuracy to replace existing regional systems.

5. The position determination system should, as an optimum method for economy and effectiveness, be integrated with a satellite mobile communication system.

6. Coverage is initially required between 70° N and 70° S latitude with polar-region coverage to be added for the 1980's.

7. Accuracy needed for the system should be about 200 meters.

8. A more effective forum is needed to enable users to state their requirements and to provide for national coordination. International coordination and standardization also are urgently needed to provide adequate service to users.

9. Innovative research and development are required to provide integrated navigation and communications services, to improve techniques for equatorial and polar accuracy, and to reduce costs.

Recommendations concerning navigation and position determination include the following:

1. *Research and development should be directed toward techniques that are needed for establishing an economically viable maritime satellite position determination system.*

2. *A demonstration project should be conducted jointly by government and industry users in order to evaluate the integration of satellite communications and position determination in maritime mobile uses.*

3. *The U.S. Department of Transportation should exercise leadership in establishing a national policy on position determination and should consult with other government agencies, with users, and with other maritime interests.*

4. *Immediate action should be taken to convene an international forum to agree on a global position determination system and to arrive at a plan to bring the system into being.*

5. *A continuously available global position determination system of sufficient accuracy should be developed and implemented to replace existing regional systems.*

6. *Applications research and development should be conducted to determine an effective system for providing position determination service in the polar regions.*

COMMUNICATIONS

Conclusions that pertain specifically to communications are as follows:

1. Current communication services available to maritime users do not meet the needs for modern marine operations.

2. An adequate forum for users to express their needs does not exist and an improved forum is needed.

3. Marine users often are skeptical of new technological systems and a demonstration capability is needed to facilitate commercial implementation and to optimize benefits.

4. During the past 5 years a number of studies and experimental programs have been conducted on the use of satellite techniques in maritime activities. The results of these efforts make available considerable information.

5. Basic technology to implement satellite maritime service is available but additional specific applications research and development are required.

6. Experiments which have been completed or which are scheduled in the near future will offer innovative use of satellite capabilities in maritime communications. These have been done primarily with shipping companies and similar programs in other areas are desirable.

7. Implementation of a commercial satellite maritime system in mid-1975 by a U.S. consortium covering the Atlantic and Pacific Oceans will provide a means for long-term evaluation of techniques, both technological and managerial.

8. To derive maximum benefits, the operational system should be extended as soon as possible to be worldwide (between 70° N and 70° S latitude). Such global service must be reliable, continuously available, and cost effective.

9. Polar-region coverage of communication services will be required in the 1980's.

10. While current radio-frequency allocations are adequate, additional spectra will be required in the 1980's.

Recommendations concerning communications include the following:

1. *Operational maritime satellite communications systems should be extended to provide worldwide coverage.*

2. *Research and development should provide a basis for significantly greater and more economical satellite power sources and improved satellite antennas.*

3. *Concurrently with spacecraft improvements, industry should develop shipboard terminals that are compatible with satellite maritime communications facilities.*

4. *Techniques and a demonstration program should be developed to provide communications services in polar regions and should include the potential applications available with multi-service satellites.*

FUTURE TECHNOLOGICAL DEVELOPMENT

The Panel on Marine and Maritime Uses has summarized its findings concerning technological capabilities that must be developed in order to make feasible proposed applications of space systems to current maritime needs. The following developments in specific capabilities are recommended:

1. *Low-light-level mapping systems for ocean bioluminescence surveys.*

2. *Systems to conduct quantitative chlorophyll-mass surveys.*

*3. *All-weather and global systems to measure sea surface temperature to about ±0.2° C and salinity to about 2 parts per thousand with a resolution of 1 km.*

4. *Systems to determine ocean wave spectra and wave diffraction patterns, which depend on bottom topography.*

5. *Systems for mapping the sea bottom to depths from 30 to 50 m.*

*6. *Systems to determine global surface-wind fields to ±10 percent or to less than 5 m/s in speed and to ±0.35 radians in direction.*

*7. *Imaging radar systems to monitor sea ice and open-water areas in the polar regions.*

8. *Systems to monitor positions of offshore facilities to within 30 to 50 m.*

9. *Simple and low-cost ($10,000) systems for continuous global voice and data transmission from ships between 75° N and 75° S latitude.*

10. *Simple and low-cost ($10,000) systems for continuous global ship position determination between 75° N and 75° S latitude and to 200 m near congested areas and to 2000 m for open oceans.*

*11. *Systems to detect heavy rain areas over the open oceans.*

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*Similar capabilities are recommended in the *Report of the Panel on Weather and Climate* (Supporting Paper 1), *Practical Applications of Space Systems*. National Academy of Sciences, Washington, D.C., 1975.

In addition to the foregoing specific capabilities, the Panel further recommends that:

13. *Followup experiments including in situ measurements be carried out to prove the feasibility of the proposed technical developments.*

14. *A central data management facility for marine use be established and that data (voice, teletype, cargo and ships status, time of arrival, etc.) be transmitted as is the case for normal teletype traffic.*

INFLUENCE OF THE SPACE SHUTTLE

Many of the needed ocean observations can be made only from satellites on polar orbits. Further, in those cases where the observation must be made in the visible portion of the spectrum, the polar orbits must be sun-synchronous. Geostationary orbits are needed for some marine monitoring, particularly for the measurement of coastal circulation. Until the space shuttle system can place satellites in polar orbits and in geostationary orbits, conventional launch vehicles will be needed if the needs of the maritime community are to be met. Long-term needs for data on sea surface temperature and salinity may be the only factors which will influence the development of the space transportation system. Polar-orbiting systems, which must monitor the oceans on a near-daily basis with resolutions of about 1 kilometer, will require microwave antennas of 100 to 200 meters in extent since the L-band (salinity) and the S- to C-bands (sea surface temperature) are the frequencies to be used in observations. Aside from the potential problem with these large antennas, a fully developed space shuttle system having polar and geostationary orbit capability appears adequate to accomplish the marine monitoring anticipated during the remainder of the twentieth century.

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