PREDICTED OPERATIONAL REQUIREMENTS
FOR A
NONMILITARY TRAFFIC COORDINATION AND NAVIGATION
SATELLITE SYSTEM

Prepared For

National Aeronautics and Space Administration
Washington, D. C.

Contract No. NASw-809

Final Report

By

James W. Campbell

TECHNOLOGY AUDIT CORPORATION
1725 K Street, N. W., Washington, D. C.

TAC #107-10

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SUMMARY

Existing navigation and communications systems, in the areas of the world in which they are installed, meet the current needs of the nonmilitary navigator for position fixing. There are, however, many areas in which navigators must depend on celestial navigation, accepting the fact that there will be many times during which adverse weather conditions will prevent the visual observation of the navigational stars. Existing or proposed electronic navigation systems could be installed to provide global coverage in the case of the VLF systems(Omega and Delrac) or essentially global coverage in the case of Loran C. None of the electronic navigation systems include a data transmission capability as an integral part of their operations.

The needs of the traffic coordination and control agencies for position information about the aircraft or ships under their cognizance are now met by the transmission of position reports at specified times by the navigator. Air traffic control position reports are required by the regulations of the national or international organization operating the traffic control system. Voluntary position reports may be submitted by surface ships to appropriate traffic coordination agencies, such as the Atlantic Merchant Vessel Report (AMVER) system operated by the U. S. Coast Guard; it is estimated that about 50% to 60% of the ships in the Atlantic participate in the AMVER system by providing a position report about once every two days.

The projected increase in transocean aircraft operations over the coming years is quite large. Under present traffic loads and using existing navigation and radio communications facilities there are peak traffic periods during which trans-Atlantic flights must be diverted either laterally or vertically to avoid conflicts in the use of available airspace. These diversions represent a departure from the minimum time path (MTP) for the flight and result in an econmic penalty to the aircraft owner. As this transocean traffic increases there will be an increasing need for a navigation system covering the ocean areas of the world and a reliable means of ground-air-ground communications for the transmission of control directions.

Other governmental agencies are concerned with the collection of data in remote areas of the oceans of the world and some of the more inaccessible land areas. Improved data acquisition and transmission capabilities would

facilitate the operations of the meteorologists and oceanographers of the world, allowing a more comprehensive analysis of the weather and, ultimately, better forecasts of future weather and sea conditions.

There appears to be a need for a global and all weather navigation satellite system to meet the present and future requirements for air and sea operations. The cooperative satellite systems, which would include a limited data transmission capability, might also meet many of the presently unfilled needs for collection and transmission of weather and oceanographic data on a global basis.

Estimating the future capacity requirements for a global cooperative traffic coordination and navigation system depends on predicting the future composition and distribution of the world air and sea fleets. The assumptions used in making these predictions are stated explicitely in Section VII of this report. Later estimates of system capacity requirements may be made as additional data become available using either present assumptions or other assumptions then deemed more appropriate.

I. INTRODUCTION

The information in this report is based on formal and informal discussions with senior scientific and technical personnel from a number of government agencies, trade associations, equipment manufacturers, etc. No attempt has been made to reconcile the often conflicting views of these individuals, nor is it intended that the information contained in this report be construed as representing the official position of any agency. It is believed that this report will be most useful in providing background information and as a point of departure in future discussions.

The present report incorporates material contained in the eight interim reports that have been prepared during the course of this research study. Some of the less essential detailed information contained in the interim reports has been omitted.

Predicted Operational Requirements

Operational requirements change over a period of time reflecting the increasing complexity and interactions of the problems that must be solved. The orderly evolution and development of the systems needed to meet the problems of the future requires a forecast or prediction of what these problems will be. This will then allow the prediction of future operational requirements, recognizing that these requirements may differ both qualitatively and quantitatively from those of the present. This differentiation between present and predicted requirements is most useful in defining the problems of the future that will only be solved by systems that are qualitatively different from those currently used; those systems that require technological advance in addition to or in place of evolutionary improvement of existing systems.

Future Marine and Aviation Activities

The past growth in the population of the U. S., which parallels that in the rest of the world, will undoubtedly continue in the future. The demands for marine and air transportation will, in turn, show a comparable increase in passenger miles and cargo ton miles, with perhaps a smaller proportional increase in the numbers of ships and aircraft needed to serve these transportation needs. Similarly, satisfying the food requirements of the world will depend to a greater degree on the potential resources of the world's oceans.

More ships and aircraft will be utilizing the sea and air space of the world, imposing additional demands on traffic coordination and control to provide safe and efficient civilian surface and air operations. Improved coordination and control of the surface and air traffic will be needed to avoid traffic conflicts or unnecessary restrictions in traffic capacity of some portions of the traffic system. The pattern of growth of air and sea traffic may be forecast in a number of ways; perhaps the simplest and most defensible forecast assumption is that the growth will be exponential in nature and will follow the pattern of the recent past (e.g. FAA traffic forecasts are now essentially exponential projections). The exponential growth assumption will be employed in this report to predict the future growth of marine and air transportation and of the fishing fleets of the world.

Navigation and Traffic Coordination and Control

The civilian navigator operates under all weather conditions on the high seas or in the airspace in all parts of the world and must periodically determine his position, and dead reckon his position between these position fixes. Agencies responsible for the coordination or control of sea and air traffic must know the position of the craft under their cognizance and be able to predict their positions at interim times based on periodic position reports from the craft. Under present methods and procedures the individual navigator fixes his position by use of celestial navigation or one of the electronic navigations systems, and then uses radio communications to report his position at specified times to a traffic control or coordination agency. There are many areas of the world in which electronic navigation systems do not exist. Similarly, many ships and aircraft are equipped with only the most rudimentary of navigation equipment. Adverse weather and cloud cover may prevent the use of celestial navigation techniques for days at a time, forcing reliance on dead reckoning during the interim period.

The various electronic navigation systems (e.g. Loran, Decca, etc.) provide the all weather position fix capability in those areas of the world in which they are installed, providing that the ship or aircraft has the necessary user equipment available. However, there is no system currently in operation that can provide global coverage with essentially uniform accuracy. The traffic coordination or control agency must rely on voluntary or compulsory voice radio position reports.

A navigation satellite system appears to offer many potential values in terms of providing the nonmilitary navigator, both air and sea, with a global system of virtually uniform position fix accuracy. Some classes of cooperative navigation satellite system may be postulated in which the position information relative to a specific ship or aircraft would be readily available to the traffic coordination or control agency without any action on the part of ship or aircraft crew, thereby eliminating the position reporting requirement. These cooperative navigation satellite systems could include the capacility for limited transmission of data between the shore based station and the ship or aircraft, which could be required to transmit control directions or to coordinate rescue operations on the high seas.

The data acquisition and transmission capability inherent in a cooperative navigation satellite system may also be useful for other purposes. Meteorological and oceanographic observations could be made and transmitted to the governmental agencies concerned with the measurement and prediction of weather and sea conditions. Unmanned meteorological or oceanographic stations could be developed to observe and transmit synoptic measurements of critical parameters.

Acknowledgments

The study of the operational requirements of the nonmilitary navigator was performed under the sponsorship of the National Aeronautics and Space Administration. A number of industry and trade groups were most helpful in providing assistance in the development of the information presented in the various technical reports, and summarized in this paper. Representatives of the Federal Aviation Agency, US Coast Guard, Maritime Administration, US Coast and Geodetic Survey, Weather Bureau, and the Bureau of Commercial Fisheries were most helpful in discussing their requirements. Messrs. Alton B. Moody and A.M. Greg Andrus, the National Aeronautics and Space Administration project officers, should be given special recognition for their intense interest and leadership in this project.

II. NEED FOR AN INTEGRATED TRAFFIC COORDINATION AND NAVIGATION SYSTEM

If the operational requirements of the nonmilitary navigator are restricted to the determination of the position of an aircraft or ship, there does not appear to be any urgent need for navigational systems in addition to the presently available or projected electronic systems such as Loran C, Omega or Delrac. There is, however, a real need for frequent and accurate position information about ships and aircraft for the use of traffic control or coordination and regulatory agencies, a need that is only partially satisfied by present or proposed systems. At least one class of satellite navigation system, those utilizing ground stations for controlling access to the satellite and to perform navigation fix computations (discussed in Section VI of this report) appears to combine these two functions, position fixing and position reporting, in a manner that will minimize vehicle equipment costs and produce an efficient and effective navigation system.

Position Fix Accuracy and Frequency

The information collected from the various classes of nonmilitary navigators, marine and air, indicates that the vast majority of their navigational requirements do not require extreme precision; in fact, a navigational error of one nautical mile with a 0.95 probability available in any part of the world and under all weather conditions would be adequate. Further, it should be possible to secure a position through the use of navigational systems at any time of the day or night, with an occasional delay of a few minutes being acceptable. If the supersonic transport (SST) is not included as one of the potential users of the system, the requirement for continuous availability of fix information could be reduced to providing a navigation fix every 10 or 15 minutes. The marine nonmilitary navigator would be able to use a system that would provide him with a navigation fix about every 1 to 2 hours.

One of the most critical problems for control and coordinating agencies such as FAA and the USCG is accurate and timely information about the position of ships and aircraft. None of the present or proposed electronic systems provide this information and rely on position reports from the vehicle. In the case of aircraft in US airspace, the position information is now being provided in some areas by Air Route Surveillance Radars (ARSR) and will eventually cover practically all of the United States at altitudes of 5,000 feet or higher. The corresponding position information system for marine traffic in the North Atlantic relies on voluntary reports by ships and aircraft, with only 50% to 60% of the surface ships cooperating. Ship owners require that their ship masters report their positions periodically, usually through one of the marine radio services.

The separation of aircraft navigation and the air traffic control position determination could lead to critical delays in aircraft action in a potential collision situation. Thus, the pilot of the aircraft may have position data that do not agree with comparable data in the air traffic control system, and the air traffic control system data may be more accurate than that in the aircraft. Ideally, these data should be in agreement, allowing more effective control of the aircraft from the ground.

The ultimate navigation system for the use of non-military navigators should combine the determination of position information on the vehicle and the dissemination of the same information to control or coordination agencies on the ground. If feasible, the system should include a communication capability for the transmission of critical control messages from the ground to the vehicle.

The accuracy requirements of the non-military navigator, with the exception of a few highly specialized operations, could be met with a position fix accuracy of one nautical mile with a 0.95 probability. Aircraft navigators also need a frequent heading reference. The special requirements of the marine mineral or oil exploration survey will depend on having the degree of relative accuracy available with optical survey techniques; actual mining and oil drilling activities will require navigational accuracies of the order of tens-of-feet. While the requirements for mineral and petroleum marine activities on the high seas do not yet exist in fact, the probability is very high that they will be critical in the next few decades.

The hydrographic and oceanographic survey ship which is engaged in operations of critical national and international importance presents another highly specialized navigation requirement in that some of the survey work, such as gravimetric studies, require high accuracy and virtually continuous coverage. These requirements, which in themselves may justify a much more accurate system, lead to the conclusion that the ultimate navigation system should provide varying degrees of accuracy depending on the needs of the user.

In the opinion of the ship and aircraft operators, equipment reliability and maintainability is a fundamental requirement of any navigation system, and is not being met satisfactorily by present electronic systems used by the non-military navigators. The engineering design of equipment should take into account the mean time between failure for the components, and should provide a period of months of failure free service. The trouble shooting part of maintenance should be aided by the use of self-checking circuits, trouble lights, etc. The replacement of failed components or sub-assemblies should be no more complex than changing a radio tube or the removal and replacement of a module. None of the maintenance tasks performed on the ship or aircraft during a voyage or flights should require the use of a soldering iron or the use of complex test equipment in making equipment adjustments.

The power required to use the ultimate navigation system are quite critical for the small single-engine aircraft, and are sometime critical in multi-engine general aviation aircraft. Weight and volume should also be held to minimum values.

Search and Rescue System Requirements

Search and rescue problems may be grouped into two categories; data transmission and position information. A large part of the communications requirement could be met by means of data link handling digital information while other communications could be reduced to an efficient numerical code. Information about the current positions of ships and aircraft is required in the preparation of surface pictures and the coordination of the search for missing craft.

There is a need for data exchange between the shore and the craft involved in the search and rescue operation. If there were a complete file of current position information available on shore, there would be no requirement for the transmission of these data from the distressed craft to the shore, but there would be a need to transmit this information from the shore to the craft assisting in the search and rescue operation. The craft in distress would need to notify the shore of the existence of the distress situation and be ready to use radio communications to provide factual information about the incident. It would be quite useful to provide the shore with an initial evaluation of the situation by indicating whether the incident was urgent or of a less critical nature. Craft engaged in a search or assistance operation could use search vectors although the availability of the positions of all of the craft involved would allow independent planning of the search or navigation to the rendezvous point. If an aircraft is in distress and may have to ditch, it would be most desirable to provide the aircraft with a heading vector that will take it to the vicinity of the assisting ship in order to reduce the time between ditching and the arrival of the ship at the scene of the ditching. It may be desirable to provide the shore with the ability to notify the craft in a position to provide assistance that it is being called on the radio and perhaps the frequency on which communications are desired.

The search and rescue system requires an accurate summary of the current position of ships and aircraft under their cognizance, using dead reckoning methods to update all positions periodically. However, if positions were updated with sufficicient frequency, and information were available as to the course and speed of the craft, the dead reckoning requirement could be reduced to those craft in the vicinity of a distressed craft. The effectiveness of search and rescue operations would be increased by including a greater proportion of ships and aircraft in the system and by improving the accuracy of the position information available to those making decisions relative to the craft best able to provide assistance.

Search and rescue operations require an improved data acquisition and data transmission capability. Given this capability, the agencies responsible for the coordination of search and rescue activities would have more accurate and timely information available for their use and would allow more efficient utilization of the ships and aircraft providing assistance.

Meteorology, Oceanography and Weather Routing

An integrated traffic coordination and navigation system would offer an opportunity to augment the data collection and transmission activities of meteorology, oceanography and weather routing services. However, it then becomes necessary to consider the three classes of data requirements as part of a single system, rather than as separate problems. Such an overall priority list would provide maximum utility and an economical data collection system. The priority list presented in Table I represents a consensus of competent meteorologists, oceanographers and scientific personnel developing ship routing methods. Among the factors considered in excluding or including a specific parameter was the feasibility of making the required observation automatically or the reliability and accuracy of estimates made by ship or aircraft personnel.

The first group of surface weather and sea characteristic observations in terms of priority include barometric pressure, sea surface temperature and air temperature. Of virtually equal importance is wind speed and direction with the requirement that these shipboard measurements be taken at a location that would provide an accurate measure of the relative wind over the deck. It would be most desirable to include an indication of the presence of precipitation and an estimate of sea state and direction in order to provide a verification of the weather and sea predictions that had been made at a prior time. Ship course and speed would be desirable, but not critical, in that the ship's course and speed made good could be determined by reference to preceding position fixes.

The collection of data from aircraft presents a different class of problem. Aircraft flying long distances, and particularly when flying over the ocean, will fly at a constant pressure altitude using a standard altimeter setting of 29.92 inches, and will be therefore at a constant barometric pressure throughout the enroute phase of the flight. The value that does change is the "D-value" or the difference between elevation of the aircraft and the pressure altitude at that point and is determined by the difference between elevation as measured by a radio altimeter and the altitude as measured by a pressure altimeter with a zero correction of 29.92 setting. Under present procedures the aircraft personnel will compute the D-value based on the estimated position of the aircraft and the elevation of the surface at that point. The aircraft will then report each hour giving its position, time, radio and pressure altitude, air temperature, wind direction and velocity as estimated, and significant meteorological conditions including icing, turbulance, etc.

The aircraft could report radio and pressure altitude and air temperature at the time of a position fix, and indicate the presence of icing or turbulence during the interval between fixes. The D-value could then be computed, assuming that the aircraft was flying at the pressure altitude assigned to it.

Table I. Meteorology and Oceanography Observation Requirements

Class of Data	Surface Ships	Aircraft
Barometric Pressure	Yes	Yes, might use flight plan pressure altitude
Radio Altitude	Not applicable	Yes
Air Temperature	Yes	Yes
Sea Surface Temperature	Yes	Not applicable
Wind Direction, relative	Yes	Desirable
Wind Speed, relative	Yes	Desirable
Course and Speed	Desirable	Desirable
Sea State and Direction, estimates	Yes	Not applicable
Significant Meteorological Conditions		
Precipitation	Yes	Yes
Icing	No	Yes
Turbulance	Not applicable	Yes
Clear Air Turbulence	Not applicable	Yes

These observations would supplement existing data collection programs and could provide additional data in many of the areas of the world now inadequately covered, the "sparse data" areas. Synoptic weather charts would be more complete while weather and sea state forecasts could be expected to become more accurate.

With these data available, it would be possible to prepare synoptic weather reports and the existing trend in the weather, taking into account the observations made by ships and aircraft. Weather and sea forecasts could then be prepared, with later data available to check on the accuracy of these forecasts of weather and sea state. If desired, the original routing could be modified as additional information became available and more accurate forecasts of weather and sea state could be made.

Need For an Integrated Traffic Coordination and Navigation System

In summary there appears to be a requirement for an integrated system serving the needs of the individual aircraft or ship navigator, the agencies responsible for the coordination or control of air and sea traffic, and of the agencies concerned with the measurement and prediction of weather and sea conditions throughout the world. It appears that many of these requirements could be satisfied by a cooperative satellite system performing the navigational functions and the data acquisition and transmission functions needed by these agencies.

III. NAVIGATIONAL REQUIREMENTS OF NONMILITARY NAVIGATORS

Background

The definition of the navigational needs of the nonmilitary navigator is complicated by the fact that navigational techniques and systems exist that are quite satisfactory when they are available for use. Celestial navigation using a sextant will provide adequate position information to the navigator providing that weather conditions allow the navigator to see the navigational stars. Electronic systems, such as Loran A, Loran C, Decca, etc., provide adequate position information in the areas that are covered by the systems (see Section VI). Proposed electronic systems, such as Omega and Delrac, could provide world-wide coverage with adequate position accuracy, if they are implemented. In the case of U. S. aviation, dependence is placed on the navigational aids provided by the FAA in accordance with national policy.

The major requirements to be met by a navigation system to be used by nonmilitary navigators are all-weather and global coverage, equipment reliability, low equipment cost and minimum manpower demands. The needs of the different classes of nonmilitary navigators are discussed in later sections of this chapter.

There have been a number of studies by U. S. marine and aviation technical groups over the past years in which statements were developed and proposed as being definitive of the operational needs of the various classes of air and surface navigator. Some of these meetings, such as the International Meeting on Marine Radio Aids to Navigation (IMRAN) in 1947, included representatives of a number of nations; others, such as Special Committees 30 and 35 of the Radio Technical Commission for Marine Services (RTCM) and Special Committee 50 of the Radio Technical Commission for Aeronatucis (RTCA), reflected the views of the U. S.

The reports and recommendations of these committees, with respect to marine requirements, are of considerable interest and value, although the recommendations of the several committees may differ substantially, even over a period of a few months. Special Committee (SC) 30 of RTCM in its report dated 23 July 1957 advocated the navigation accuracy in the US IMRAN position or 1% of distance to danger at long range (defined as over 50 Miles). SC 35 IRTCM in its report, dated 17 December 1957, proposed an accuracy requirement of 0.5 miles or less 95% of the time for all marine users except private craft, for which it recommends an accuracy of 1 to 2 miles 95% of the time. The British position at IMRAN called for 1% of the distance to danger or 5 miles, whichever is lesser, on ocean passage.

A review of the recommendations of comparable committees in the field of aviation navigation requirements, such as those included in IMRAN and the meetings of the Communications Division of the International Civil Aviation Organization (ICAO) in Montreal in 1962, indicates a similar lack of agreement as to the absolute accuracy needs of aviation.

The Navigation Problem

The navigator must know his position relative to the surface of the earth at all times in oder to determine the future course of his ship or aircraft to reach his desired destination safely and efficiently. The next portion of the the trip may have to be modified to avoid some natural or man-made obstacle. Knowledge of his vehicle's position may be essential in search and rescue operations. The control or coordination of surface or air traffic requires accurate and timely data as to the position of all vehciles being controlled. A pre-planned route must be followed to minimize cost and to achieve a desired time of arrival at a destination Measures that can be used to evaluate navigational effectiveness include safety and "near misses", decreased operating cost, reduced time for a transmit, etc.

The operations performed by the nonmilitary navigator run the gamut from conning a pleasure craft through well-marked and familiar waters to piloting a jet or supersonic aircraft across oceans. In some ways the needs for navigation information appear to be incompatible in terms of the position fix accuracy requirements, the time available to complete the navigation fix, manpower available and qualified to make the necessary observations and calculations, and the amount of money that can be invested in equipment, maintenance personnel, facilities, etc.

If requirements are limited to the determination of an aircraft or ship position, it must be recognized that many methods and systems exist today or are in active development to satisfy the needs of the nonmilitary navigator. Current operational electronic systems do not provide global coverage, although additional Loran C stations could be sited to provide "usable accuracy" in most parts of the world. The Omega system under development by the Navy Electronics Laboratory of the Bureau of Ships, U. S. Navy, promises to provide both global coverage and good accuracy under all weather conditions. The distance covered by the Omega signals (with a theoretical minimum of six stations to provide world wide coverage) includes the problem of predicting diurnal shift in signal timing. The Delrac System, proposed by the Decca Navigator Company, Ltd., could also provide global and all-weather coverage.

The nonmilitary navigator, and particularly those engaged in commercial operations, needs to know his location; but there are also other groups that require information about his position. The various electronic systems may provide this location data, but the navigator must communicate this location data to others, an action which may or may not be taken voluntarily. For example, the U. S. Coast Guard operates the AMVER (Atlantic Merchant Vessel Reporting) system to keep track of ships on the North Atlantic; there are many ships (of the order of 40% to 50%) that do not provide necessary position data to the USCG. (See Section IV).

The present methods used in traffic coordination rely on the use of a number of different systems with more or less overlap of functions between the systems. There are different and incompatible electronic navigation systems in different parts of the world. The needs of the traffic coordination agencies for position information depends on the nonmilitarty navigator providing periodic position reports with no positive check on the accuracy of these position reports. The traffic coordination systems relying on voluntary radio position reports (such as the AMVER system) do not include all of the ships and aircraft and may also use inaccurate position information in their operations. The capital investment and operating cost of these navigation and communication systems is high and may increase considerably to meet the future needs of the nonmilitary air and surface operations.

<u>Classes of Nonmilitary Navigator</u>

The nonmilitary navigator will fall into one of three broad groups; Those in the sea and air transportation systems, the fishing fleets of the world or one of the highly specialized sea operations such as oceanographic or hydrographic survey ships. General aviation (which includes pleasure and business aircraft), although not engaged in commercial transportation, should be included in that these aircraft use the controlled airspace of the world. Pleasure boats, with a few exceptions, operate in inland waters or near to the coast in pilot waters and therefore have little need for a long distance navigation system; those desiring to do so will purchase equipment apporpriate to the smaller ship or the fishing boat such as radar, Loran, etc.

The major classes of nonmilitary navigator considered in this research study include the following:

Surface:

- Commercial ships
- Cable layins ship
- Survey ships
- Fishing boats
- Mining & petroleum operations
- Pleasure craft

Aviation:

- Air carriers, fixed wing
- Air carriers, rotary wing
- Supersonic Transport (SST)
- General Aviation, US
- General Aviation, World

Position Fix Accuracy

The present and projected operational needs of the various classes of nonmilitary navigator were discussed in some detail in the earlier TAC report "Nonmilitary User Requirements for Navigational Information" and are summarized in Table II. In essence, this report indicates that the nonmilitary navigator will need a global, all-weather system of navigation that will provide him with a position fix at any time of the day or night. The accuracy requirement for his position fix will depend on the particular operation in which his ship or aircraft is engaged. The vast majority of these needs could be met by a system that would provide a 0.95 probability that his observed position would be within one nautical mile of the actual position of his ship or aircraft. However, some of the smaller classes of nonmilitary navigator requiring maximum accuracy (such as the hydrographic or oceanographic survey ship) are engaged in operations that are of such national or international importance as to justify a much more accurate system.

The introduction of the supersonic transport (SST) into the air transportation system will impose new requirements on air navigation.* The SST will require navigation in three dimensions due to the inter-relations between aircraft weight, altitude and fuel consumption. The SST in the cruising environment will operate at altitudes above the conventionally known jet stream winds, allowing the SST to follow the great circle route to its destination much more closely than is possible with the subsonic jet aircraft;

*See **Navigation**, Journal of the Institute of Navigation, Spring 1963 (Vol. 10 No. 1) for technical papers presented at the Supersonic Transport Seminar, cosponsored by the Institute of Navigation and the Institute of Science and Technology of the University of Michigan, Jan. 15-16, 1963, Ann Arbor, Michigan.

TABLE II. FORECAST OPERATIONAL REQUIREMENTS OF NONMILITARY NAVIGATORS

Operational Activity	Coverage Area	Weather	Position Fix Accuracy	Frequency of Position Fix Min.	Frequency of Position Fix Max.	Critical Equipment Characteristics Reliability	Weight	Power	Cost
Marine									
Commercial	Global	All	1 n.m.	60	180	Critical			Critical
Cable Laying	Global	All	1/2 n.m.	60	180	Critical			Important
Survey-General	Global	All	1 n.m.	30	60	Critical			Important
Survey-Special (e.g. depth, gravity, etc.)	Global	All	50-100 ft.	5	10	Critical			Important
Fishing	Global	All	1 n.m.	60	180	Critical	Important	Important	Critical
Mining & Petroleum	Global	All	10-50 ft.	30	60	Critical			Important
Pleasure	Coastal	All	1 n.m.	60	180	Critical	Critical	Critical	Critical
Aviation									
Air Carriers Fixed Wing	Global	All	1 n.m.	5	30	Critical	Important	Important	Important
Air Carriers Rotary Wing	Continental	All	50-100 ft.	5	10	Critical	Critical	Critical	Important
Air Carriers, SST	Global	All	1 n.m.	5	10	Critical	Important	Important	
General Aviation, US	US	All	1 n.m.	15	45	Critical	Critical	Critical	Critical
General Aviation, World	Continental	All	1 n.m.	15	45	Critical	Critical	Critical	Critical

Kelly estimates that about 85% of the SST requests for clearance will ask for the great circle route. The envelope of minimum time tracks (Figure 1) is taken from a paper presented by Cdr. Curtis J. Kelly, USCG, of the Federal Aviation Agency at the Supersonic Transport Seminar and shows the restricted area in which the SST may desire to operate. Precision navigation, utilizing either an external navigation system or an on-board equipment requiring periodic correction (such as doppler radar) will be required in order to achieve the minimum time track with the SST.

The SST will operate at subsonic speeds during the climb to and descent from the supersonic cruise environment, and will have to operate in the same airspace as other subsonic aircraft. The high fuel consumption in the climb phase (estimated to be about 400,000 pounds per hour during the ascent to cruise environment) will probably impose severe operational and cost penalties on the SST unless the traffic control activity and all aircraft have accurate position and altitude information during the entry and departure of the SST from US airports and controlled airspace.

There is a critical problem in the relationship between the agencies providing navigation services and the nonmilitary navigator using these services. For example, an agency can provide an advisory service for the information of the ship or aircraft, and there is complete freedom on the part of the navigator to use or not use the information on the basis of his best judgment. The shore-based agency may evaluate the situation that exists in the air or on the sea and provide recommendations as to the "best" action that the nonmilitary navigator could take under the circumstances. Control directions, as used by air traffic control activities, can be issued to the aircraft; failure to follow the directions as issued would be justified at a later time with possible disciplinary action should the facts of the case warrant such action. The ship master has a long tradition and numerous legal decisions behind his position that he is the only person responsible for the safety of his ship; either the recommendation or control relationship would be contrary to this tradition. Aircraft operations, and particularly those of the air carriers, have developed within the control relationship and the use of advisory services. It would therefore appear that the basic need is for an advisory relationship between the shore based agency and the nonmilitary navigator.

The nonmilitary navigator needs to know his position periodically, the interval between position fixes being dependent on the operation in which he is engaged. In almost every case the navigator maintains a plot of his ship

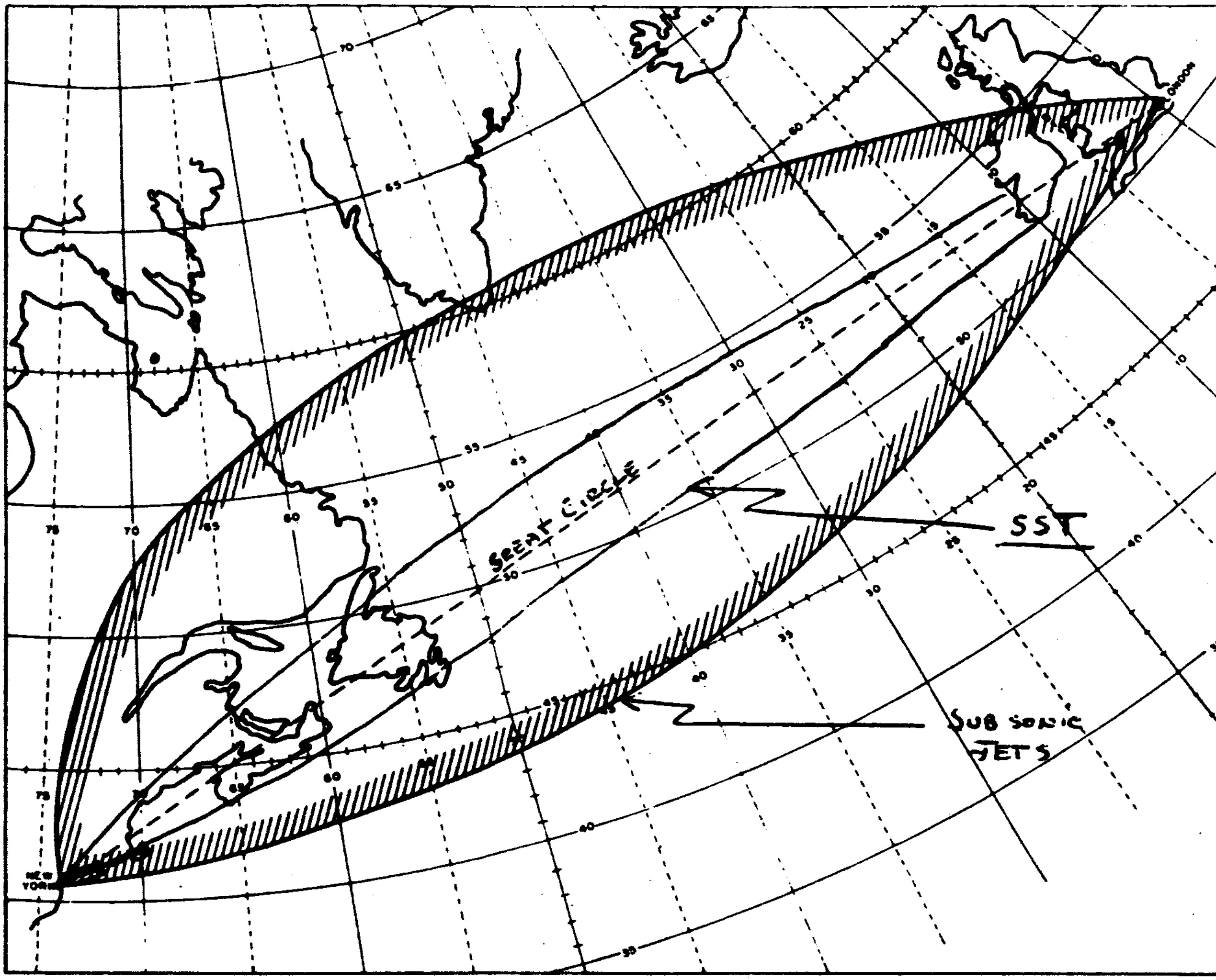

Figure 1 - Envelope of Minimum Time Tracks - 300 Millibar Level

or aircraft, including the determination of the course made good and the distance traveled. The location of navigation hazards will be determined by the use of an appropriate chart, and usually while maintaining the dead reckonking plot on the chart. The location of other traffic will be determined by means of radar or by direct visual observation; it is necessary to plot these observations over a period of time in order to determine the relative motion of this traffic and to determine the collision hazard that may exist.

Agencies responsible for the control of the movement of air and sea traffic require, in addition to all of the data needed to recognize an impending collision situation, information about the identity, future course and destination of the individual ships or aircraft under their cognizance. If the agency provides an advisory or coordination service to ships or aircraft within its area of cognizance, it would probably refrain from the evaluation of collision probabilities among these craft. The transmission of critical informatioon between the coordination or control agencies and the ships and aircraft under their cognizance must be accurate, reliable and timely, and now is performed by use of radio communications.

Air Traffic Control

Air traffic control over the land masses of the world is less difficult than is air traffic control over the ocean areas of the world. Air navigation aids, such as VOR or VORTAC, may be installed to provide required coverage in spite of the line of sight limitations of the VHF systems. Radio communications between the aircraft and the ground may be accomplished by use of the VHF or UHF channels available. Surveillance radar systems, such as the Air Route Surveillance Radar (ARSR) system of FAA, may be used to provide aircraft position information to the traffic control system.

The rapid increase in air traffic across the Atlantic in the years following World War II has exceeded the estimates of normal growth. The expansion between 1950 and 1961 exceeded 250%. Some estimates of the 1975 traffic forecast traffic in excess of three times the 1961 traffic. Peak days during 1961 involved over 400 flights, about equally divided between divil and military aircraft.

The desires of the traveller for convenient arrival and departure hours now lead to peak periods during which more aircraft are entering the controlled airspace over the Atlantic than can be accommodated without diverting the aircraft to some route other than the one requested. When diversions are made, the aircraft may be diverted either laterally or vertically. If the diversion is lateral, the trip will be somewhat longer than the desired minimum time path and will cost more in terms of fuel cost and flight time. If the requested altitude is changed, and usually by having to fly at a lower altitude, there will be an increase in fuel consumption for the flight.

Air traffic control over the oceans of the world, and particularly over the Atlantic, cannot be based on VHF and UHF systems or on the use of surveillance radars. High frequency radio may be used to carry most of the communications traffic, but there will be instances in which ground-air-ground communications will have to be relayed by other aircraft for surface ships. Self contained navigation systems such as doppler radar or inertial systems may be used, providing that the systems are reset periodically by means of position fixes made with other systems (e. g. Loran, Consolan, Decca, etc.). The need for a long term solution to the transoceanic air traffic problem is well recognized and currently under study by FAA.

An air traffic control activity requires, in order to perform its functions, timely and accurate position information for the aircraft being controlled, the intentions or flight plan for each flight, a means for communicating control instructions from ground to air and verifying that these instructions are being followed, and the timely identification of actual or potential conflicts in the use of air space.

Aircraft Position Data

The safe and efficient utilization of airspace requires that the control activity know the position and altitude of all aircraft at all times. In the case of transocean air traffic control, this position is based on periodic position reports originating in the aircraft; propeller aircraft are required to report their positions every 5° of longitude and jet aircraft every 10°. The error in the predicted position of an individual aircraft results from errors in the position fix on which the position report is based, delays in receiving a position report, and the length of time covered by the prediction. These predicted position errors can be quite large and are reflected in the separation standards employed for transocean flights.

The contribution of the original position fix error to the predicted position error is obvious. The length of the prediction period is critical in that the aircraft (1) may depart from its planned course or change course during the time interval, (2) may alter its speed by changing the engine power setting or entering a new temperature environment, or (3) may experience an emergency during the time interval. Thus, any delays in the transmission and/or reception of the position report, as well as the period of time between position reports, will have an impact on the magnitude of the predicted position error. The accuracy of the predicted position may be improved by means of more precise position fixes, reduced delays in the transmission of this information from the aircraft to the air traffic control activity, and by more frequent position reports.

Control Directions

Voice radio is now the primary system for air ground communications, with HF radio used for oceanic communications. Problems arise from the number of different frequencies used for these communications and the unreliability of these communication links over the oceans during some period of the year. In addition, the aircraft personnel must monitor continuously certain radio channels which will carry messages for all aircraft within a specific area. The controller also spends a substantial portion of his time communicating with other persons within the air traffic control center and with other centers, thus limiting the time he has available for assessing traffic information and making the required decisions.

IV. SEARCH AND RESCUE

The overall objective of the search and rescue (SAR) system is to provide assistance to ships and aircraft in distress through maritime mutual assistance. The individual search and rescue operation will be initiated on learning of a distress condition in a ship or aircraft, and may be learned of indirectly by the failure of the ship or aircraft to arrive at its destination (or an intermediate reporting point) on time. The SAR operations in the Atlantic may be considered to be indicative of what can be accomplished with existing navigation systems and communications facilities.

Under present operating conditions in the North Atlantic, the distress message will be received by the USCG shore or ocean station radio and delivered to the Coast Guard Rescue Coordination Center. The cognizant agency for the distress situation will be notified and the required action initiated, and other agencies notified of their role in the operation. If the operation requires a search for a craft or the diversion of a ship or aircraft to assist the distressed craft, the Coast Guard AMVER (Atlantic Merchant Vessel Report) system will prepare a surface picture (presenting the dead reckoned position of ships and aircraft in the vicinity of the distressed craft) for transmission to the distressed craft by the Coast Guard Radio. The distressed craft will then attempt to establish direct communications with one or more of these other craft in order to effect the mutual assistance.

SAR Search Costs

Civil aircraft may be diverted from their planned flight path to participate in the search for a distressed ship or aircraft, but the major portion of these search flights are conducted by Coast Guard, Navy and Air force aircraft. Both the Coast Guard and Air Force have aircraft squadrons with SAR responsibilities. Additional SAR missions will be flown by other Air Force and Navy squadrons as required, including SAR flights within the mission of all of the squadrons.

It is possible to identify all aircraft SAR operational hours for Navy aircraft squadrons through the use of normal reprting procedures and statistical analyses that are routinely made. Similarly, the Coast Guard is able to identify SAR operational hours for their aircraft. In the case of the Air Sea Rescue squadrons in the Air Force, a review of the past several years of data available in the form of statistical summaries indicates that from 25% to 30% of the flight hours in these squadrons is on SAR missions, with the remaining 70% to 75% devoted to other classes of mission including training, orbits, etc. Other AF squadrons will, when the need exists, assign aircraft to SAR activities, but will not identify these hours in statistical summaries of their activities.

The total of 27,308 flight hours included in this analysis do not include all of the flight time devoted to this activity in that only a portion of the Air Force flight hours can be identified. The magnitude of the error is indicated by the fact that the search for the C-124 in the Pacific during January, 1964 accounted for over 3,000 SAR flight hours over a three week period; the average SAR mission hours for AF ASR Squadrons is estimated to be 7,000 per year.

The cost of flying SAR missions depends on the type of aircraft used and the basis for assigning costs. At one extreme, the cost of a SAR flight could be limited to the cost of fuel, oil and non-technical expendable supplies; such an estimate would be very conservative and would omit many important charges such as maintenance, amortization of the cost of the aircraft, crew cost, etc. At the other extreme is the charge for an aircraft that would be made to a nonmilitary user of the military aircraft in accordance with the directives issued by executives within the services or the Department of Defense; while these costs may be a little high, they are probably closer to the true cost of the flight hours of these aircraft to the US. The latter costs will be used in this analysis.

Five different aircraft account for over 90% of the identifiable 27,308 SAR mission hours flown during a 12 month period; these aircraft were the C-54, C-130, HU-16, P-2 and the P-5. A total of 22 other aircraft types were employed to fly the remaining 2,196 SAR mission hours. Table III following does not identify the specific aircraft or service to permit this material to be unclassified. (See next page).

Table III. Annual SAR Flight Hours

Aircraft	SAR Hours Flown	% of SAR Hours	Estimated Cost/Hour	Cumulative SAR Cost (Millions)
A	17543	64.2	$339.00	$5.95
B	4421	16.2	226.00	6.95
C	1080	4.0	236.24	7.20
D	1042	3.8	468.62	7.69
E	1026	3.8	415.00	8.12
F	733	2.7	91.09	8.18
G	307	1.1	365.00	8.29
H	290	1.1	166.40	8.34
I	217	.79	77.00	8.36
J-AA Incl.	649	2.4	312.25*	8.56

*Weighted value of charges for selected aircraft.

Present Operations

There are three major elements needed in search and rescue operations: radio communications, stored position information for ships and aircraft, and tested methods for coordinating the search phase. Other elements of the search and rescue operation which involve the evaluation of the facts of the distress situation and the decision as to the actions to be taken are the responsibility of the cognizant agency.

Communications

The Coast Guard Ocean Station Vessels provide a relay point for radio communications between ships and aircraft on the high seas and the shore. While this element of the total system meets practically all of the present communication requirements, there are instances in which an incident will occur which will be learned by the failure of the ship or aircraft to arrive; a recent case is the loss of the Sulfur Queen in 1963. Fishing boats may not return on schedule or there may be a delay in receiving a routine position report from an aircraft flying across the ocean. The major problem is that of determining the approximate location of the missing ship or aircraft at the time of the distress situation and the length of time between the incident and learning of the situation.

Position Information

Some ships and aircraft operating in the North Atlantic provide information to the AMVER system on a voluntary basis, but it is estimated that only 50% to 60% of the ships participate; for example, the AMVER plot during June, 1963 included an average of 792 ships with a maximum of 851 ships one of the days. If a ship provides a position every 15° of latitude, the dead reckoned position of the ship is estimated to be in error by at least 25 miles. However, the average position error is estimated to be about 50 or 60 miles, and there may be instances in which the dead reckoned position is literally hundred of miles in error. The surface picture prepared by AMVER includes these errors in the positions of ships and aircraft; a ship asked to provide assistance may not be the closest to the distressed craft and will have to search 8 or 9 thousand square miles of open ocean. If there has been any appreciable delay in learning about the distress situation, the search area may be measured in hundred of thousands of square miles (over 800,000 for the C-124 search in January 1964). The value of accurate position information at the time of a distress incident is indicated by the search for the jet tankers that collided over the Atlantic in August, 1963. In this incident, the position of the crash was known to within a 10 mile square; the wreckage was located in between 3 and 5 hours flight time.

Coordination of the Search Phase:

Aircraft usually conduct the search for missing ships or aircraft frequently at considerable distances from shore. There may be a problem in navigating the search plane to the search areas as well as the problems of relocating the distressed craft after it has been found. If the search zone covers a large area, a number of aircraft will conduct the search with some overlap in the area covered by the individual aircraft.

V. METEOROLOGY, OCEANOGRAPHY AND WEATHER ROUTING

The World Meteorological Organization (WMO), through its member nations, collects synoptic weather reports from a large number of land and mobile observation stations. The ships selected to provide these synoptic weather reports provide four such observations each day; many sea areas of the world are not covered by these reports. Synoptic weather charts are prepared from these reports; weather forecasts are then developed for varying periods of time for the use of those concerned with the predicted future weather and its impact on activities.

Oceanography is still a relatively young science concerned with the study of the oceans and all that they contain. The short range uses of oceanography include the prediction of ocean waves and winds, with an immediate application in the routing of ships along paths that will avoid adverse conditions and produce more efficient utilization of ocean shipping. Similarly, the interchange of energy between the atmosphere and the hydrosphere at the interface will determine the future weather and sea conditions. Longer term problems include those of more accurate knowledge of the life of the sea and its cultivation as a major source of food for the expanding population of the world in the future.

The close interrelationship of meteorology and oceanography is indicated by the extent to which both of these sciences depend on measure of current weather and sea conditions to describe the present situation and to predict what future conditions will be. Serious gaps exist in the network used for the collection of the required data, both in the matter of geographical coverage and, to a lesser degree, the number of observations that are now made in the areas currently covered.

Ships and aircraft travelling over long distances take the anticipated weather into account in order to minimize the time of the trip and to reduce the potential dangers arising from adverse weather. These flight or voyage plans are based on the use of weather forecasts and, in the case of ships, on predictions of the seas that will be encountered in various segments of a voyage. The aircraft flight covers only a few hours of time, and will usually be at high altitude; the supersonic transport will be operating well above the currently used flight levels during the supersonic cruise phase of a flight. The primary concerns in determining a minimum (or minimal) time path for a specific flight are the expected winds, the temperatures in which the aircraft will operate and avoiding areas in which turbulence or icing will occur. Shipping companies are making increasing use of weather routing services in planning voyages to avoid high seas and winds. The Military Sea Transportation Service (MSTS) estimates that their ships achieved an average reduction of 14 hours per voyage in over 1000 transoceanic crossings over a two-year period.

Operational Requirements

The importance of meteorology and oceanography in ship and aircraft operations is probably greater than would appear to be the case at first glance. The interface of the sea and the air produces the phenomena that determine the present and predicted weather and sea conditions. Aviation and marine operations cannot be planned effectively without considering what future conditions will be; the aircraft will seek favorable winds and temperatures, while the ship will seek to avoid adverse seas and winds. It therefore appears to be both necessary and desirable to consider these global environmental data collection requirements as an integrated whole rather than as separate problems. The collection of these data from mobile or fixed stations, either manned or unmanned, are all part of the same fundamental problem of securing more complete geographical coverage of the world and, to a lesser degree, of securing additional observations within the areas now included within the data collection network.

Meteorology

The major operational activity of meteorology is weather forecasting, but meteorological research is not solely concerned with the improvement of weather forecasting techniques. The more basic objective of meteorological research is that of improving the knowledge of the atmosphere and its behavior; this improved knowledge will, in turn, lead to improved ability to predict the weather and perhaps for a longer period of time.

A major operational problem in meteorology is the collection of critical weather data over the land and sea areas of the world, and to then use these data to describe the weather and its dynamic change with time. The problems associated with the coordination of weather observations throughout the world, and the standardization of the parameters measured, has led to the development of the synoptic meteorology program within the World Meteorological Organization of the United Nations. There are a number of land stations throughout the world (primarily in the northern hemisphere) and selected ships that make the required synoptic weather reports and forward the reports to national and regional data collection centers. These reports, based on observations at 0000,0600,1200 and 1800 GMT, include rainfall, maximum and minimum temperature, wind speed and direction, visibility, present and past weather in standard categories, barometric pressure including trend and rate of change, dew point, clouds by type, amount, height of base and direction of movement and sea and swell for ships. Some reporting stations will make an additional four observations each day half-way between the synoptic times. Radiosonde observations of the atmosphere are also made at some locations to collect upper air data for use in weather predictions and for aviation forecasts. Radar is also used to track balloons and to observe weather over a large area, while rockets are sometimes used for collecting data at high altitudes.

A major future requirement for weather data collection is that of providing more complete coverage in all areas of the world and perhaps to increase the frequency with which these measurements are made. Additional coverage and more frequent observations from these stations (either fixed or mobile) could result in improved accuracy of forecasts and, perhaps, extending the period of the weather forecast beyond those now used. The future methods of transmitting weather data from the observation station to the regional data collection centers will require more rapid and efficient data transmission techniques. The present use of high speed electronic data processing systems will be expanded.

Oceanography

The science of oceanography is still young, but is quite active in building up knowledge of the oceans and their contents. The present report is primarily concerned with those aspects of oceanography having to do with weather and the travel of ships over the seas; i.e., the impact of the ocean on the climate of the world, and the interaction of the seas and the atmosphere.

The oceanographer needs, in addition to the data included in the synoptic weather report, a number of measures including such parameters as sea surface temperature, water salinity, currents, etc. The small number of ships participating in the synoptic meteorological program (about 2,100 at this time), the fact that ships are at sea only a part of the time, and the concentration of shipping on the major trade routes of the world, places a severe restriction on the amount of data available to the oceanographer and meteorologist. Oceanographic survey vessels actively engaged in ocean research will also report under the synoptic meteorological program when they are at sea.

Weather Routing

Meteorologists and oceanographers have developed methods subsequent to World War II for forecasting waves by use of synoptic weather forecasts using wind speed and direction and the fetch of the wind (or the expanse of the ocean over which a wind travels). Prognostic wave charts are now prepared by use of the five-day sea level pressure predictions issued by the U. S. Weather Bureau. Sea state observations made by the selected ships reporting under the Synoptic Meteorology Program are used to prepare synoptic wave charts.

The routing agency, either governmental or commercial, is faced with the problem of predicting those sea and weather conditions that will affect the movement of ships across the seas of the world; the critical sea conditions are those that will force a ship to reduce speed either because of sea conditions, wind or visibility. The critical sea conditions are those of wave height and sea surface temperature; wave height in its direct effect on ship speed, and sea surface temperature in its effect on visibility by production of fog. The critical weather condition is wind; through the development of sea waves (as opposed to swell) over distance and time, and by a direct but small reduction of ship's speed by blowing against the ship. Waves and wind must be predicted both in terms of the magnitude and direction since a bow wind or sea will produce a greater reduction in ship speed than either a beam or following wind or sea; in fact, a following wind may actually produce a small increase in ship speed. The ship performance curves in waves of various heights for a VC2-AP3 vessel (figure 1) reflect both the environmental factors causing speed reduction and the voluntary decrease in speed by the master to ease his vessel.

The weather routing service will use the five-day sea-level prognostic weather chart series prepared by the Extended Forecast Section of the U. S. Weather Bureau to prepare a five-day prognostic wave chart.

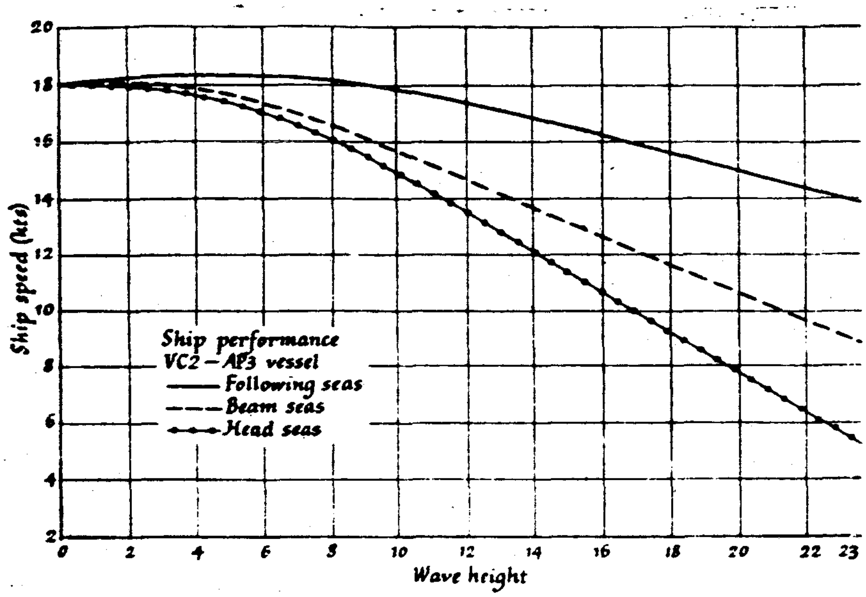

Figure 2 - Ship Performance Curves

Source: "Optimum Ship Routing" by G. L. Hanssen and R. W. James, Journal of the Institute of Navigation, July 1960.

The synoptic wave charts, based on the observations made over large areas of the sea, are also employed in preparing the prognostic wave chart. Wave height isopleths and the direction of major wave trains are shown, allowing an estimate of the impact of sea conditions on the proposed route of a specific ship. Wave height and direction will be predicted on the basis of the predicted wind speed and direction, the length of the fetch, and the calculation of swells from the current synoptic wave charts. If the ship's voyage is longer than the five-day period covered by the weather forecast, the U.S. Weather Bureau 30-day outlook, weather analogues and statistical wave conditions in the area are used to determine the probable route for the later stages of the voyage; the suggested route will be reviewed as new weather forecasts are used to prepare prognostic wave charts and the necessary corrections made in the route for the ship. Should the voyage cross an area in which significant ocean currents exist (usually defined as persistent currents with a speed in excess of 1/2 knot), the currents will be included in the calculations.

The U. S. Naval Oceanographic Office is now experimentally predicting sea conditions directly from the Weather Bureau forecasts of the surface pressure patterns over a five-day period. However, the basic problem in improved forecasting of sea conditions is that of improved weather predictions, and the ability to track storms on a more detailed basis and to associate the storm track with the wave charts and ship-speed charts in time and space. It may also be anticipated that present manual methods of route forecasting will ultimately be replaced by the use of electronic computers and data processing systems.

VI. EXISTING AND PROPOSED NAVIGATION SYSTEMS

The groupings used in a study of navigation systems depend on the interests of the investigator or study group. During the 1947 International Meeting on Marine Radio Aids to Navigation (IMMRAN), the major emphasis was placed on the general location of the vessel and was defined as pilotage waters, coastal waters, or the high seas (i.e. over 50 miles from nearest danger). The Federal Aviation Agency (FAA) studies of air navigation in US airspace consider the en route areas and terminal areas as being of primary importance. Operations in international airspace fall primarily into the en route area category, since the ascent and descent phases of an international flight would be regulated by some government.

The analysis of nonmilitary navigation requirements leads to the conclusion that the ultimate navigation system will have to provide global and all-weather coverage for the various classes of navigator, and that the Supersonic Transport (SST) would need essentially continuous coverage by its navigation system. For these reasons the present study of navigation systems places major emphasis on those classes of navigation systems that could provide essentially uniform global coverage. The major groups of navigation systems and their general characteristics are as follows:

Celestial Navigation

The use of sextants for measuring the elevation angles or altitudes of celestial bodies has been employed for many years and is essentially the basic system for position fixing. The skill of the navigator in making his observation and the care with which he makes his calculations will determine the accuracy of his position fix. The stability of the vehicle being navigated sets an upper limit on accuracy. Any use of visual observations is, of course, impossible during adverse weather conditions.

Radiosextant

The use of the radiosextant for navigation can be considered as analogous to the use of the sextant for visual observation of the altitude angle of the sun and moon. The radiosextant involves the use of an accurately stabilized directional antenna, presenting operational and maintenance problems in nonmilitary applications. The cost of these systems is quite high at the present time. One of the major advantages of the radiosextant would be its ability to use either the sun or moon or a satellite with a suitable radio beacon as a celestial reference body.

Radar

There are two general classes of radar that are of interest to the navigator, the usual radar with a plan position indicator (PPI) presentation and the doppler radar that is sometimes used for aircraft navigation. In this report, secondary radar systems are considered to be a form of electronic system. The PPI presentation is of major value in pilotage situations, but does not provide positional information unless identifiable ground reference points are included in the area scanned. The doppler radar, while of considerable value in aircraft, is not usable by surface or sub-surface vessels.

Electronic Systems Using Ground Based Transmitters

Over the years, a large number of electronic systems have been developed or proposed. The hyperbolic systems, and particularly those utilizing the lower radio frequencies, could provide global coverage with "usable accuracy" as well as very high accuracies within 1,200 to 1,500 miles of the base line. The systems based on bearing measurement do not provide sufficient accuracy while the VHF and UHF have the line-of-sight range limitations inherent in these frequencies. Loran-C and the proposed Delrac and Omega systems appear to be the most effective of the electronic systems in providing all weather and global coverage.

Inertial Systems

Some military aircraft and ships use inertial navigators, employing various other systems to periodically update and correct the inertial navigator. The cost of these systems is very high, and the maintenance and operator skill demands require the availability of highly qualified and well trained technicians.

Geophysical Pattern Matching

Geophysical phenomena such as gravity, magnetic anomalies, water depth, etc., could be used to determine the location of a vehicle. The difficulty in measuring these phenomena, and particularly from aircraft, leads to instrumentation problems including cost and reliability. Prior surveys would also be needed.

Navigation Satellite Systems

A number of different classes of navigational systems using satellites could be developed. In essence, navigation satellite systems may be based on the measurement of either the elevation or azimuth angle from the vehicle to the satellite, the range to the satellite, or the changing range rate as measured by doppler shift of a standard frequency or frequencies from the satellite. Other techniques are also possible. The functions performed by the satellite in any of the systems will have a direct influence on the expected satellite life; the more varied and complex the functions carried out by the satellite, the shorter the period before one or more of the essential satellite equipments fail. The orbital life of the satellites is less critical, for even the low altitude satellites used in the range rate systems will have an orbital life far beyond the expected life of the electronic equipment in the satellites.

Some of the satellite systems could be designed to use ground stations to control access to the satellite and to perform the necessary calculations to determine the vehicle position. It now appears that these "cooperative" systems may provide a means of materially simplifying the satellite and vehicle equipment with corresponding improvement in satellite life, lower vehicle equipment cost and improved reliability.

The bonus features associated with some of the navigation satellite systems may be of considerable operational value. The range rate systems could provide an accurate time standard; the altitude system could provide an accurate heading reference. The cooperative systems, by virtue of having performed the navigational computations, could provide position information about all vehicles in the system for distribution to those with an operational need for such data. The cooperative systems could provide a data link from the ground stations to the vehicle via the satellite which might also be used for certain critical classes of communication.

Systems for More Detailed Analysis

Some of the general classes of navigational systems can be eliminated from further consideration on the basis that they would not provide the all-weather capability, would be excessively expensive for the nonmilitary navigator (including operating and maintenance costs as well as initial cost), or could not provide the necessary accuracy in all parts of the world.

Celestial navigation using an optical sextant can be eliminated since it is not an all-weather system. Inertial navigation systems, at least at the present state of development, would be extremely expensive and difficult to maintain, particularly for the nonmilitary navigator. Geophysical patterns matching navigational techniques will probably be limited to a few highly specialized applications, primarily military. Doppler radar can be eliminated as it cannot be used by surface ships.

The remaining classes of navigational systems will be considered in some detail.

Electronic Navigation Systems

Navigation systems have used measurement of various characteristics of radio transmission. Perhaps the earliest of these used a directional antenna to measure the bearing to a radio transmitter at a known location, giving a line of position, two or more such bearings locating the navigator at the intersection of these lines. Later systems were developed in which the time of travel of a sound and radio or light signal from two or more transmitters was measured and the location of the navigator determined by these ranges. Still other systems have been based on the measurement of time differences in the travel times of signals, these time differences defining hyperbolas of equal time difference.

A complete catalogue of the electronic systems that have been proposed was beyond the scope of this research study, if only on the assumption that a proposed system failing to gain sufficient acceptance for test and evaluation need not be re-examined for merit. Similarly, the systems that have been superseded were of only passing interest in this study. The present report will include only major operational systems and the proposed VLF systems. The short range systems used primarily for survey work will not be included.

Bearing Measurement Systems

A number of systems have been developed in which the vehicle measures the azimuth angle of one or more transmitters to secure a line of position to the transmitter. In general, these systems are limited in range and the position errors at long ranges are quite large. The technical problems associated with the accurate measurement of bearings by use of a directional antenna limits accuracy under operational conditions as indicated by a standard deviation of about 0.4°, but many bearing measurement systems in operational use are much less accurate.

Range Measurement Systems

The measurement of range by timing the transmission and return of a signal is the basis for a number of systems. In most cases the signal is returned through a transponder system at two or more known locations. In the case of radar, the signal return is primarily due to reflection, although reflectors or transponders may be used to augment the signal.

Hyperbolic Systems

The measurement of differences in the time of receipt of transmissions from transmitters of known location in which there is fixed time delay between the signals can be used for navigational purposes. The time difference defines hyperbolae with the two stations at the foci. Two such station pairs (including, perhaps, a station common to both pairs) will then provide intersecting hyperbolae, thereby determining the location of the vehicle. The angle of intersection of the hyperbolae is critical in determining the accuracy of the position fix. Navigation charts are provided for the Decca and Loran systems; the scale of the charts limits the accuracy of position determination whereas the tables used in preparing the charts may be used by the navigator. The radio frequency used in the hyperbolic systems is critical in the range coverage, while the base lines determine the intersection angle of the hyperbolae; a VLF hyperbolic system such as the proposed Omega or Delrac systems could provide both world wide coverage and favorable intersection angles, very close to 90°, in all parts of the world. Brief descriptions are presented of Decca, Delrac, Loran and Omega.

Decca

An operational system with a range of about 240 miles, which the British have advocated as the standard world-wide system. The system is quite easy to use and provides high accuracy within its ranges. Various accessory equipments are available, one of which is the Track Plotter and its various charts. The Track Plotter may be used for ship conning in restricted waters or in periods of restricted visibility.

Delrac (Decca Long Range Area Coverage)

A proposed VLF system that could provide global coverage with about 21 station pairs. Estimated accuracy is 10 nautical miles (0.95 probability) at the worst locations. There would be no vehicle limitations. Provision is made for solving the lane ambiguity.

Loran-C

This is an operational military system with 17 stations in operation in 1961. The Loran-C system was developed from the CYTAC system navigation equipment. Accuracy is about 0.25 miles within the area covered by the ground wave and about 5 to 10 miles within the area covered only by the skywave. Ground wave coverage is available to distances of about 1500 miles. Loran-C could provide "usable accuracy" (5 to 10 miles) in about 80% to 90% of the world with about 70 stations.

Omega

A proposed VLF system being developed by the U. S. Navy. There may be a problem in lane ambiguity in aircraft, and particularly high speed aircraft; current jets can cross through about 75 lanes per hour, while a Mach 3.0 supersonic transport would be within an 8 mile lane for only a few seconds. The Omega system would provide virtually uniform accuracy (about 1 mile) in any part of the world. In theory, 6 Omega stations could provide global coverage; the availability of land for the ground stations would probably increase this number to about eight.

Navigation Satellite Systems

There have been a number of proposals for the application of satellites in the development of navigation systems for civilian use. While these proposed systems may be feasible from an engineering point of view, the real question is "What kind of system is needed to meet the operational requirements of the potential users of such a system?" The decision to build a new system should be based on satisfying real operational requirements for which existing systems are inadequate or inefficient. In some cases, a new system might be justified in that it could combine a number of separate functions into a single integrated system with improved effectiveness and reduced cost.

There are a number of different system concepts that could be used to meet the need for nonmilitary navigation and traffic coordination. Of these, which are most suitable for the civilian application? The critical question to consider is that of the operational needs of the civilian navigator for position fixes in accordance with the requirements of the particular activity in which he is engaged. The needs of the traffic coordination or data collection agency for periodic position reports from the ships or aircraft under its cognizance are an essential part of the operational requirements.

Navigation satellite systems can be grouped according to the nature of the measurements made with reference to the satellite. The satellite traveling in its orbit follows a somewhat predictable path, with periodic corrections needed to adjust for unknow components of perturbations occuring over time. Thus, the position of the satellite can be determined at any time, the accuracy of the position depending on the precision with which time is measured and the accuracy of the orbital prediction. The relative position of the navigator with respect to the satellite can then be determinedmined by measuring the altitude (elevation angle), azimuth angle (bearing), range to the satellite, or the rate of change of altitude, azimuth or range. If a single variable is being measured, successive measures separated in time will be required or simultaneous measures using multiple satellites. Independent measures (e. g., range and azimuth) made simultaneously will allow the use of a single observation in determining the vehicle position. All of these techniques are used to develop the lines of position of the vehicle, and the intersection of these lines of position determines the position.

Altitude Measurement

These systems would be comparable to the usual celestial navigation procedure, substituting a satellite of known position for a celestial body. The altitude angle of the satellite can be measured either by direct visual observation or by the use of a suitable radio beacon in the satellite. A navigation satellite system would undoubtedly measure the altitude by use of a radio beacon since visual observations would be restricted by cloud cover and visibility of the satellite. The navigator would have to know time with considerable accuracy and would have to measure the altitude angles to 1 minute of arc or better to secure a position accuracy of one nautical mile. The antenna used to measure the altitude angle would require precise vertical stabilization in addition to providing the required pointing accuracy. Advance knowledge of the satellite position would be needed for acquisition of the satellite. A satellite centered system using an interferometer for angle measurement would require accurate data about the satellite attitude at the time of the observation.

Altitude/Altitude Rate

These combined measurement systems appear on first examination to offer instantaneous position determination. However, the altitude rate determination would have to be based on the integration of observation over a period of time, making these systems operationally equivalent to the altitude measurement systems. Satellite position would have to be known in order to acquire the satellite.

Altitude Rate

Integration of altitude measurements over time could be made to determine the rate of change of the altitude angle. In doing this, it would then be possible to use relative antenna stabilization, rather than absolute stabilization to the true vertical, during the period of observation. However, the simplification of the antenna stabilization problem would be achieved at the expense of placing more critical demands on other parts of the system. Advance knowledge of the satellite position would be needed in order to acquire the satellite.

Azimuth

Lines of position could also be based on the azimuth angle of the satellite. Antenna motion would be quite critical and would require accurate north and vertical stabilization. Angular resolution of approximately the same order of accuracy (1 minute of arc or better) would be needed as in the altitude measurement systems. Advance knowledge of the relative position of the satellite would be needed in order to acquire the satellite.

Azimuth /Azimuth Rate

The systems are the operational equivalent of the azimuth systems since the measurement of azimuth rate would have to be based on the integration of data over a period of time.

Altitude/Azimuth

It would be possible to measure the altitude and azimuth angles simultaneously, allowing the navigational fix to be made with a single observation. The antenna would have to provide very high resolution in both altitude and azimuth, and would probably be more difficult to aim in the original acquisition of the satellite. Advance knowledge of the satellite position would be needed for aiming the antenna.

Range Measurement

The distance between the navigator and the satellite could be determined by phase comparison or measuring the time for transmission of a radio signal. The ranging signal would be retransmitted by a radio transponder in the satellite. Range measurements can be made quite accurately, providing good range resolution at a reasonable cost in system complexity.

Range Rate Measurement

The changing range of the satellite can be used to locate a ship or aircraft. If the doppler shift of reference frequencies transmitted by the satellite is used, it is necessary to use curve matching techniques in order to determine the position of the craft. A second method could measure range rate by measuring the time between two signals transmitted by the satellite and comparing this with the actual time between the signals. A measure of range rate could also be made by subtraction of two successive range measures, although this would be the operational equivalent of the range measurement system.

The major problem in the doppler systems is the relatively low altitude of the satellite, of the order of 600 to 900 miles, needed to secure an adequate shift in the frequency. This in turn introduces problems in the prediction of the satellite position for a period of several hours and making these predictions available to the navigator for his use. If the orbital data are provided through the satellite, it becomes necessary to incorporate adequate memory and programmers in the satellite.

Range/Azimuth

The simultaneous measurement of range and azimuth and/or elevation angle would allow the instantaneous determination of position of the ship or aircraft. If the angle measurement is centered on the craft, the highly directional antenna must be accurately aimed for acquisition of the satellite and accurate stabilization data is required for use during the observation. If the angle measurement is centered on the satellite it would be necessary to have accurate information about the satellite attitude at the time of the observation, data that could be available at a centrally located ground station.

Range Rate/Altitude

The combining of altitude and range rate measurements offers independent measures of position, but would require a period of observation in measuring the range rate. The high resolution directional antenna used in the svstem would require very accurate vertical stabilization. Satellite acquisition would be a major problem.

Other Possible Systems

There are a number of other sytems that could be studied. For example, the satellite could transmit a fixed beam pattern, with beams at every 90°. The satellite would have to be accurately stabilized, allowing the navigator to determine his position by timing the receipt of two successive signals. Another comparable system would use a rotating beam. In fact, systems can be postulated in which any two or more variables (including altitude, altitude rate, azimuth, azimuth rate, range, range rate) are measured.

Cooperative Systems

Some of the techniques could be based on the use of the satellite to retransmit signals between the vehicle and a ground station. Access to the satellite could be controlled by the ground station, providing a method for avoiding saturation of the satellite equipment and multiple response problems. The orbital data about the satellite would be used only by the ground station, eliminating the need for the publication of satellite almanacs, the dissemination of orbital correction information, etc. All computations and measurements could be performed at the ground station, thereby avoiding the need for computational facilities or operations by the navigator, and materially simplifying the equipment installed in the nonmilitary vehicle. The satellite functions would be reduced to serving as a reference point and retransmitting signals, eliminating many of the complex functions that would otherwise be required.

Of perhaps greater importance are the bonus features that would be associated with a cooperative system. For example, the ground station would know the position of all vehciles using the navigation satellite system, and would be able to distribute this position information to other groups needing such data, including traffic control agencies, for use by search and rescue activities, the ship or aircraft owners, sea surveillance, etc. Similarly, the availability of the data link in such a system could be employed for some classes of critical communications.

Comparison of Possible Classes of Navigation Satellite Systems

The characteristics of the above classes of navigation satellite system can be described with sufficient precision at this time to permit an initial evaluation. This was accomplished by several well qualified individuals familiar with these possible systems independently comparing the basic systems with respect to each of system performance factors. Table IV summarizes the results of this evaluation. The rating steps used in this comparison are summarized by assigning the numbers from 0 to 3, as follows:

0	Impossible	Cannot be accomplished with the system
1	Undesirable	Extremely difficult to accomplish with a system in terms of equipment complexity, cost etc. A critical characteristic which may well limit the utility of the system because of technical problems.

2	<u>Average</u>	Neither desirable nor undesirable; the problem can be solved but there are less complicated solutions available in other systems.
3	<u>Desirable</u>	The solution of the problems is relatively simple and straight forward, with no serious penalty in equipment cost or complexity; one of the reasons for selecting a system over competing systems.

Conclusions

The navigational requirements of the nonmilitary navigator could be satisfied by existing or proposed electronic navigation systems, if these requirements are restricted solely to position determination. The VLF hyperbolic systems could provide global coverage and all-weather operation. Of these systems, Omega appears to meet the navigational accuracy requirements, but the Delrac and Loran-C systems might provide increased accuracy in some locations. However, none of the electronic systems will provide vehicle position information to ground stations as an integral part of the system operation, but would depend on the vehicle providing such data on a voluntary basis.

The result of this evaluation indicates that the cooperative systems offer considerable potential value in meeting the needs of the nonmilitary navigator and of the traffic coordination agencies for a traffic coordination system. The navigator could have accurate information available in all parts of the world and under all weather conditions. Similarly, the traffic corrdination agencies could have accurate position information available for their use, and would be able to direct more of their efforts to the exceptional situation requiring decision and action and a lesser amount of attention to the elements of the system that are proceeding according to plan; thus traffic coordination could spend more of its efforts on "management by exception".

Table IV. EVALUATION OF NAVIGATION SATELLITE SYSTEMS

	INDEPENDENT						COOPERATIVE		
	Altitude	Azimuth	Azimuth Altitude	Range	Rate Range	Azimuth Range	Range	Rate Range	Azimuth Range
1. Antenna Requirements (ship or aircraft)									
a. Antenna Motion	1	1	1	3	2	1	3	3	3
b. Directional Antenna	1	1	1	3	3	1	3	3	3
2. Reference Variables on Vehicle									
a. Vertical	1	2	1	3	3	2	3	3	3
b. North	3	1	1	3	3	1	3	3	3
c. Time, Real	1	1	1	1	3	1	3	3	3
d. Time, Relative	3	3	3	1	1	2	3	3	3
e. Vehicle Velocity	2	2	3	2	1	2	2	1	3
3. Computation Requirements									
a. Comparability	3	3	3	2	1	2	3	3	3
b. Computer Requirements	3	2	2	2	1	2	3	3	3
4. Orbit Characteristics									
a. Orbit Prediction	3	3	3	2	1	2	3	2	3
b. Orbit Data Required by Navigator	1	1	1	1	1	1	3	3	3
5. Satellite Complexity									
a. Functions	3	3	3	2	1	2	2	2	1
b. Satellite Life	3	3	3	2	1	2	2	2	2
c. Satellite Stores Orbit Data	3	3	3	2	1	2	3	3	3
6. Navigation Coverage									
a. Global Coverage	3	3	3	3	3	3	3	3	3
b. Saturability	3	3	3	1	3	1	2	2	2
c. Observation Period	2	2	3	2	2	3	2	2	3
d. Continuous Coverage	3	3	3	2	1	2	2	1	2
e. All Weather	3	3	3	3	3	3	3	3	3
f. Limitations	3	3	3	3	2	3	3	2	3
7. Navigation Accuracy									
a. User Equipment Complexity	1	1	1	2	2	1	3	3	3
b. Uniformity	3	3	3	2	1	2	2	1	2
8. Vehicle Equipment									
a. Cost	1	1	1	3	2	1	3	3	3
b. Technological Obsolescence Potential	3	3	3	3	1	3	3	3	3
c. Weight, Space and Power Requirements	1	1	1	3	2	1	3	3	3
d. Maintainability	1	1	1	2	2	1	3	3	3
e. Reliability	2	2	2	3	2	2	3	3	3
f. Training	3	3	3	3	2	3	3	3	3
g. Automation Potential	2	2	2	3	3	2	3	3	3
h. Aircraft Limitations	2	2	2	3	1	2	3	3	3
9. Ground Stations									
a. Satellite Tracking	3	3	3	2	1	2	2	1	2
b. Data Injection	3	3	3	2	1	2	3	3	3
c. Fix Computations	3	3	3	3	3	3	1	1	1
d. Worldwide Locations	3	3	3	3	3	3	2	1	2
10. Bonus Features									
a. Data & information exchange	0	0	0	0	1	0	3	3	3
b. Traffic Control	0	0	0	0	0	0	3	3	3
c. Air-Sea Rescue	0	0	0	0	0	0	3	3	3
d. Time Standard	0	0	0	0	3	0	2	2	2
e. Heading Reference	3	0	0	0	0	0	0	0	0

VII. ESTIMATED CAPACITY REQUIREMENTS FOR AN INTEGRATED TRAFFIC COORDINATION AND NAVIGATION SATELLITE SYSTEM

An integrated traffic coordination and navigation satellite system concept would include the ability to monitor the position and progress of aircraft and ships in all parts of the world. One present formulation of the system includes the use of medium altitude satellites (about 6,000 nautical miles) and six ground stations to perform the necessary measurements and calculations. The area covered by a single satellite is quite large, which would allow one of the ground stations to provide services to ships and aircraft within a correspondingly large area of the world. However, the cooperative system concept, in which the satellite would be used to relay transmissions between the ground station and the users, would have a definite and not unlimited capacity due to the use of a digital data link. It is therefore desirable to study in some detail the traffic loads that could develop during the future years, both in terms of the probable numbers in the various classes of nonmilitary navigator, and the regions of the world in which they could be operating.

The civilian surface and aviation fleets of the world will undoubtedly increase during the coming decades. The major problem is that of defining the assumptions that are used in projecting into the future from available historical statistical data. Of these assumptions, the fundamental one, and one that applies in many situations, is that this increase will be exponential in nature barring unpredictable natural or manmade events that will significantly modify this growth. A second major assumption is that any changes in growth rate will take place slowly and over a period of many years or decades.

The coverage area of a satellite is so large that presently defined geographical areas must be grouped into larger units. Thus, a satellite with its suborbital point at Honolulu would be able to cover practically all of North America, the North Pacific Ocean, much of the eastern coast of Asia, and parts of the South Pacific Ocean, Australia and New Zealand. The geographical areas that will be used in this report are as follows: Atlantic Ocean, Pacific Ocean, Indian Ocean, North America, South America, Europe, Asia, Africa and Oceania.

The next problem is one of estimating the number of ships and aircraft that could be using the system at any time. This estimate will be based on the projected acceptance rate by the various classes of user assuming that the integrated traffic coordination and navigation satellite system becomes operational in 1970. It will also be assumed that all within a class of nonmilitary navigator who will ultimately install the necessary user equipment will have done so by the year 2000.

Projected Growth of User Classes

There have been few studies of the projected growth of the marine and aviation fleets of the world. Available statistical summaries have been used, and the growth rates indicated in these data used in making population projections through the year 2000. It is significant that these projections are generally similar to the projected population growth of the world's population prepared by the Statistical Office of the United Nations, predicting a doubling of the world population (from 3.2 to 6.1 billion) between 1961 and 2000.

The published statistical summaries for the marine and aviation fleets of the world reflect the differences in regulations of the several nations providing data and of the requirements of the international or trade agencies for which the reports were prepared. The growth projections for the various classes of nonmilitary navigator presented in Table V (see following page) should be reviewed as additional data become available in order to develop more accurate population estimates when the need arises. Special studies may be required for some of the classes such as the world fishing fleet and general aviation outside the U. S.

Major Operational Areas

The nature of the operations in which the several classes of nonmilitary navigator are engaged will determine to a considerable degree the major areas of the world in which these operations will take place. Commercial ships, and particularly the larger ones, will follow the major trade routes of the world. Fishing boats will travel to both the fishing grounds in the oceans bordering their home continents and the major fishing grounds in the Atlantic and Pacific. General aviation aircraft will normally operate in the air space of their home continent.

TABLE V - PROJECTED GROWTH OF MAJOR CLASSES OF NONMILITARY NAVIGATORS

Class of Nonmilitary Navigator	Estimated Number (thousands) 1960	2000	Source of Data and Years used in Determining Average Growth Rate
Fishing Boats	407.5	976.8	Yearbook of Fishery Statistics, Food and Agriculture Organization(FAO) of the UN, 1955-60
Commercial Ships			
1000 tons and up	17.3	42.2	Merchant Fleets of the World, Maritime Administration, U. S. Dept. of Commerce; 1955-62
100-999 tons	19.0	46.2	Lloyds Statistical Reports; 1955-62 and Merchant Fleets of the World (see above)
5-99 tons	109.8	267.5	Extrapolations using data from Lloyds Statistical Reports and Merchant Marine Statistics, Bureau of Customs, U. S. Treasury Dept.;1955-62
Aviation			
Air Carriers			
ICAO Data	4.7	9.4	Digest of Statistics No. 91, Fleet-Personnel, International Civil Aviation Organization of United Nations; 1957-61
*Form H Data	8.2	16.4	ICAO Air Transport Reporting Form, Civil Aircraft on Register Form H; 1961 using growth data from Digest of Statistics No. 91, ICAO
U. S. General Aviation	76.5	538.9	Statistical Study of US Aircraft, Federal Aviation Agency; 1957-61
World General Aviation, excluding U. S.	32.9	231.7	ICAO Air Transport Reporting Form, Civil Aircraft on Register Form H; 1961 using growth data from Statistical Study of US Aircraft, FAA

*Form H is a new reporting form issued by ICAO and completed by various countries. The present data are based on the reports of 43 countries for the year ending Dec. 31, 1961 and submitted during 1962 and 1963.

This research study is concerned primarily with those nonmilitary navigators operating in or over the broad ocean areas of the world, since this forecast will provide a basis for estimating the traffic load that an integrated traffic coordination and navigation satellite system might experience at various time in the future.

Fishing Boats: There is a trend for the larger fishing boats to operate in deeper waters and consequently at a longer distance from land, with some concentration of these new fishing grounds in the Atlantic and the Pacific. The estimated operational areas will therefore deviate to some degree from that of equal distribution of fishing boats in the oceans adjacent to their home continents.

The distribution of the powered fishing fleet and its rate of growth (from over 350,000 in 1955 to over 407,000 in 1960) has been quite stable during this six year period, as indicated in Table VI following.

TABLE VI - DISTRIBUTION OF POWERED FISHING FLEET (% of World Total)

Area	1955	1956	1957	1958	1959	1960
Africa	1	1	1	1	1	1
North America	28	27	27	25	25	25
South America	2	2	2	2	2	2
Asia	44	45	46	47	47	47
Europe	19	19	18	18	18	18
Oceania	3	3	3	3	3	3
USSR	3	3	3	4	4	4

Source: Yearbook of Fishery Statistics, Food and Agriculture Organization of the UN

If these fishing boats were equally distributed between the major oceans adjacent to these areas of the world, there would be about 40% in the Pacific, about 35% in the Atlantic and about 25% in the Indian Ocean. It will be assumed that aboug 10% of the larger fishing boats will be in the Indian Ocean, about 50% in the Pacific Ocean and about 40% in the Atlantic Ocean.

Commercial Ships: The major trade routes of the world on which the larger merchant ships operate are those moving traffic between North America, Europe and Western Asia. The U. S. Naval Oceanographic Office has published a chrt of the routes of ships engaged in U. S. trade in 1958, consolidating analyses made by that office and the U. S. Maritime Administration.

Based on this information and informal discussions with personnel concerned with these problems, it is estimated that about 60% of large commercial ship traffic will be in the Atlantic, about 5% in the Indian Ocean and about 35% in the Pacific. The small commercial ships (those between 5 and 999 tons) are more widely distributed and will generally sail over shorter distances. The values that will be used in the traffic projection for these classes are 40% in the Atlantic, 30% in the Pacific and 30% in the Indian Ocean.

Air Carriers: The air carrier flights over long distances, either transcontinental or transoceanic, are the major concern in the present research study, since these are the flights that will require a long distance navigation system and specialized air traffic control operations. Shorter distance air carrier operations will be taken into account by reducing the estimated acceptance of the integrated traffic coordination and navigation satellite system. The values that will be used in the projection of air carrier operational areas are 70% over the Atlantic, 10% over the Pacific, 15% over North America and 5% over Europe.

U. S. General Aviation: The size of the business aviation segment of general aviation (over 50% of general aviation aircraft are used in whole or in part for business transportation according to the 1962 Aircraft Owners and Pilots Association survey) indicates that at least some of these aircraft will make transcontinental or transoceanic flights. It is estimated that about 1% of these flights will be over the Atlantic and that the remainder will be over North America.

World General Aviation: Accurate and complete data for world aviation are not available; the Federation Aviation Internationale data includes only those aircraft whose owners are members of sport aviation clubs belonging to FAI while the ICAO Form H reports do not cover all of the countries of the world. In the absence of more definitive data, it will be assumed that about 60% of the non-U. S. general aviation is located in Europe, and that the remainder is distributed equally with about 10% in South America, Asia, Africa and Oceania respectively.

The estimated operational area distribution of the various classes of nonmilitary navigator developed in this study is summarized in Table VII, on the following page.

TABLE VII - ESTIMATED WORLD OPERATIONAL AREAS

Class of Nonmilitary Navigator	Atlantic Ocean	Pacific Ocean	Indian Ocean	N. Am.	S. Am.	Africa	Europe	Asia	Oceania
Fishing Boats	40*	50	10						
Commercial Ships									
1000 tons & up	60	35	5						
100 to 999 tons	40	30	30						
5 to 99 tons	40	30	30						
Air Carriers	70	10		15			5		
U. S. General Aviation	1			99					
General Aviation, Non-US					10	10	60	10	10

*Percent of class of user

Estimated Traffic

At this stage, the projected growth and operational location of the various classes of potential user of an integrated traffic coordination and navigation satellite system may be used to develop a first approximation of the possible number of users that would be serviced by the system at any one time. Additional assumptions will be required as to the initial operational date for the system, and the rate at which the nonmilitary navigators will purchase and install the ncessary equipment on their ships and aircraft. It will be assumed that the integrated traffic coordination and navigation system becomes operational in 1970, and that all of those who will use the system will have done so by the year 2000. If it is desired to estimate the number of users at some time between 1970 and 2000, one possible assumption would be that additional users will be added in accordance with the normal distribution over the thirty year period, or that 2% of the total number that will install the system will have done so by 1975, 16% by 1980, 50% by 1985, 84% by 1990, 98% by 1995 and 99.9% by 2000. The assumptions used for each of the classes of nonmilitary navigator are summarized in Table VIII, on the following page.

Table VIII. ESTIMATED UTILIZATION AND ACCEPTANCE

Class of User	Utilization Rate	Estimated Proportion using System 1970	2000
Fishing Boats	50*	2	25
Commercial Ships			
1000 tons and up	50	10	80
100 to 999 tons	60	5	50
5 to 99 tons	65	2	25
Air Carriers	40	10	50
U. S. General Aviation	5	1	20
World General Aviation	7	1	20

*Percent of class of user

Projected System Traffic Load

The population, operational area, utilization and acceptance estimates may now be combined to provide a first approximation of the possible number of position fixes that would be provided by the integrated traffic coordination and navigation system during a typical hour. Separate estimates are presented for the two years, 1970 and 2000. It is assumed that marine users will require an hourly position fix, that air carriers will have an average requirement for ten position fixes per hour and that general aviation will need four position fixes per hour. (See Table IX on following page).

TABLE IX

ESTIMATED CAPACITY REQUIREMENTS (POSITION FIXES PER HOUR - THOUSANDS)

	Atlantic Ocean	Pacific Ocean	Indian Ocean	North America	South America	Europe	Asia	Africa	Oceania
1970									
Fishing Boats	2.0	2.5	.5						
Commercial Ships									
1000 tons & up	.6	.4	.1						
100-999 tons	.3	.2	.2						
5-99 tons	.7	.5	.5						
Air Carriers	2.7	.4	N*	.6	N	.2	N	N	N
General Aviation, U. S.	N	N	N	N	N	N	N	N	N
General Aviation, World	N	N	N	N	N	N	N	N	N
TOTAL Position Fixes per hour	6.3	4.0	1.3	.6	N	.2	N	N	N
2000									
Fishing Boats	48.8	61.1	12.2						
Commercial Ships									
1000 tons & up	10.1	5.9	.8						
100-999 tons	5.5	4.2	4.2						
5-99 tons	17.4	13.0	13.0						
Air Carriers	23.0	3.3	N	4.9	N	1.6	N	N	N
General Aviation, U. S.	.4	N	N	21.2	N	N	N	N	N
General Aviation, World	N	N	N	N	1.2	7.6	1.2	1.2	1.2
TOTAL Position Fixes per hour	105.2	87.5	30.2	26.1	1.2	9.2	1.2	1.2	1.2

*Negligible