PROCEEDINGS

# THE INSTITUTE OF NAVIGATION

## NATIONAL MARINE MEETING

**Theme: New Frontiers in Marine Navigation**

## 23-24 OCTOBER, 1973

**U.S. MERCHANT MARINE ACADEMY, KINGS POINT, L.I., N.Y.**

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Co-Sponsored by:

NEW YORK SECTION OF ION

U.S. MERCHANT MARINE ACADEMY

AT

THE U.S. MERCHANT MARINE ACADEMY
KINGS POINT, LONG ISLAND, N.Y.

The Institute of Navigation
815 15th St., N.W. Suite 832
Washington, D.C. 20005

# PREFACE

The 1973 Institute of Navigation National Marine meeting was held at the U.S. Merchant Marine Academy at Kings Point, N.Y., Oct. 23-24, 1973. The meeting was co-sponsored by the U.S.M.M.A and the New York Section of the Institute. The theme of the meeting was "New Frontiers in Marine Navigation". The technical papers which were presented and which are published in this Proceedings have certainly fulfilled the criteria of this theme. They represent the forefront of technology in the varied disciplines which cover the navigation spectrum.

The all encompassing spectrum covered by the papers presented can be observed from the nature of the subjects covered:

The accuracy spectrum with a paper on a new small Boat Gyro-compass, one on mixed Inertial Systems and several papers on Electro-statically Suspended Gyro Navigators.

The alphabet spectrum with a paper on an ALPHA-OMEGA Radio Navigation System. Also one on a new technique of determining Azimuth and one on the use of a new computing aid to solve age old celestial problems involving the Zenith, among other things.

The altitude spectrum with a paper on a Doppler Sonar Log and a few on the use of Doppler Satellite Navigation. Also, a paper on Underwater Omega and the one on a calculator for Celestial Navigation.

The frequency spectrum with several papers on OMEGA at V.L.F. of 10.2 KHZ, to others on TRANSIT at 400 MHZ, to others on collision avoidance Radars involving U.H.F.

Even the historical time spectrum was covered by three of the speakers. Mr. Sleiertin of Raytheon spanned the development of Sonar systems from the Submarine Bell in 1901 to the present day. Mr. Conigliaro, President of the Sperry Division, in his luncheon talk on October 23, traced the history of the navigational systems employed on the early Polaris submarines to those being planned for the future Trident submarines. Capt. Lawrence Jarett of the U.S. Merchant Marine Academy gave a very interesting talk to conclude the meeting in which he pointed out that the time-honored doctrine of the Universal Freedom of the Seas promulgated by Grotius in 1608 is presently in great peril from new nationalistic boundary limits and economic pressures for sea-bed exploitation.

The General Chairman of the meeting was the distinguished Superintendent of the U.S.M.M.A., Rear Admiral Arthur B. Engel, U.S.C.G. (Ret.). In addition to his duties in helping to organize and host the meeting, he also made the keynote remarks opening the meeting on 23 October and introduced the luncheon speakers each day. Ably assisting RADM. Engel and perhaps the hardest working individual on the meeting committee, was Capt. Ray Eisenberg, USMS of the U.S.M.M.A.

The Vice General Chairman and a moving force in early committee activities was Mr. Marvin Taylor, the chairman of the New York Section of the Institute until his relocation to Charlottesville, Va. with the Sperry Marine Systems Division. Mr. Eugene F. von Arx, of the Sperry Systems Management Division, the present chairman of the New York Section and also the Eastern Regional Vice President of the Institute, took over Mr. Taylor's duties as Vice General Chairman during the last few months prior to the meeting.

The Technical Chairman of the meeting was Dr. Emanuel Levinson of Sperry Gyroscope Division, the Secretary of the New York Section of the Institute. Assisting in the selection of papers was Capt. Al Fiore, USMS of the U.S.M.M.A. The Arrangement Chairman was CDR. Leland Pearson, USMS of the U.S.M.M.A. The Entertainment Chairman was Mr. Lou Kramer of the Naval Strategic Systems Navigation Facility (NSSNF), the Program Chairman of the New York Section. The Publicity Chairman was Mr. Robert Leonards of NSSNF, past chairman of the New York Section. All of these Committee members came through with flying colors and performed far beyond their normal call of duty. Whoever arranged for the beautiful Indian Summer weather deserves a special commendation.

The first session, MERCHANT SHIP NAVIGATION, was chaired by Capt. Al E. Fiore, USMS, of the U.S.M.M.A.

The luncheon speaker on 23 October was Mr. Salvatore A. Conigliaro, President of the Sperry Division of the Sperry-Rand Corporation, who, as previously noted, delivered an interesting and sometimes nostalgic talk on navigation systems from Polaris to Trident.

Session II was entitled RADIO AND SONAR NAVIGATION and was chaired by Mr. Alex Cohen, the Technical Director of NSSNF.

A Banquet was held at Leonards of Great Neck on the evening of 23 October. A cocktail reception was co-sponsored by the Sperry Gyroscope Division, the Sperry Marine Systems Division, and the Sperry Systems Management Division, to whom the Institute is extremely grateful. The toastmaster at the Banquet was the always exciting Dr. Tom Nicholson, Director of the American Museum of Natural History and Past President of The Institute. The speaker was RADM. Wm. F. Rea III, USCG, Chief of the Office of Merchant Marine Safety. He gave an engaging talk entitled "Vessel Traffic Systems: on the Frontier of Operational Safety", pointing out the needs and plans for improved Vessel Traffic Control Systems.

The third technical session on INERTIAL NAVIGATION was chaired by Mr. Anthony J. Lo Faso, Chief Engineer of Navigation and Guidance Engineering at Sperry Gyroscope Division.

The luncheon speaker on 24 October was Capt. Lauren S. McCready, USMS, Director of the National Maritime Research Center (NMRC), who gave an informative talk describing the current advanced Research Projects presently being worked on at the NMRC.

The fourth, and final, technical session was entitled GENERAL NAVIGATION. This session was chaired by Capt. Edward Cassidy, USCG, Head of the Dept. of Professional Studies at the U.S. Coast Guard Academy.

Several technical exhibits were available outside of the auditorium. The Sperry "STAR" experimental ship with various equipment on display was docked at Kings Point for observation by meeting participants. Finally, several people went on a walking tour of the beautiful grounds of the U.S. Merchant Marine Academy.

Emanuel Levinson,
Technical Chairman

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VESSEL TRAFFIC SYSTEMS
A NEW FRONTIER IN VESSEL NAVIGATIONAL SAFETY

REAR ADMIRAL W.F. REA, III, U.S. COAST GUARD
CHIEF, OFFICE OF MERCHANT MARINE SAFETY

Distinguished guests, ladies and gentlemen: It's always a pleasure for me to appear before a group like this, for I feel a real sense of union in that we are all working toward a common goal: the promotion of safety of life at sea. Both the maritime community and that larger community served by maritime commerce benefit from sessions like this, and I consider it a privilege to be offered the opportunity to speak to you tonight.

The theme of this year's meeting, "New Frontiers in Navigation," is a most appropriate one. In the past few years we have seen a remarkable surge in the rate of improvement of both navigational systems and of the training of the men who use those systems. In the rush of events and advances in the art of navigation, however, we sometimes fail to realize just how much has been accomplished and, more importantly, how much is promised by the knowledge that we have gained. Accomplishment and promise are the two defining elements of a frontier in any endeavor; so for the remainder of my time with you here tonight, I would like to examine these two elements in what I consider to be one of the most exciting projects the Coast Guard has embarked upon recently, the establishment of Vessel Traffic Systems.

In order to obtain the proper perspective as we look at Vessel Traffic Systems, let's look first at the work that has been accomplished to put us on the threshold of this new dimension of navigational safety. Although the United States has traditionally been quite conservative in moving to vessel control systems, the momentum has been growing. As far back as 1951, a demonstration of the benefits of radar surveillance in a congested harbor was conducted in New York City. In 1962, New York was the scene for another experimental system, this one utilizing radio and television, but the project was terminated after three years by technical problems.

Successful vessel control systems operated by the Corps of Engineers and private groups such as pilots' organizations also fed the growing demand for a cohesive national system during the early 60's. Early systems varied in design from a vessel movement reporting system in Boston to the voluntary carriage of bridge-to-bridge radio-telephones in the Delaware Bay and River System. Each of the regional systems added to the fund of knowledge around which the present techniques evolved.

Work on a national system began in earnest in 1968 as the Coast Guard's Office of Research and Development was looking for a good place to evaluate shore based radar as an aid to navigation. At the same time, a San Francisco group was looking for help in this area and it was this fortuitous combination of government and citizen interest which led to the installation of radar to survey vessel movements in San Francisco harbor in 1969. January 1970 saw the initiation of an entirely voluntary, entirely "passive" form of vessel traffic assistance in that harbor.

While this new frontier was being explored operationally, we were doing our homework in Washington to prepare a reasonable, logical approach to the institution of a national plan for vessel traffic control.

Two major issue studies on VTS were initiated by Coast Guard Headquarters. The efforts, which amounted to nearly 10,000 man hours of exhaustive investigation, showed, among other things, that no other nation in the world has the proliferation of ports and waterways that exist in the United States. In these 200 major ports and waterways an estimated 40 million dollars are lost each year in collisions, rammings, and groundings, and as the volume of shipping grows, so does that total. The number of deaths resulting from these casualties average 56 per year, with an additional 52 persons injured. Also, in the first full year in which complete information was available, there were 116 polluting incidents caused by rammings or groundings, which spilled over 2 million gallons of pollutants into U.S. waters.

That is what the statistics told us about the navigational safety record in our major ports and waterways. Congress told us to improve it.

With the signing of the Ports and Waterways Safety Act in July 1972, the Coast Guard was mandated by the people of this country through their representatives to improve safety and environmental quality in our harbors and inland waterways. This effort would have to synthesize the best we had in technology, training, and not incidentally, government leadership. We had accomplished much to reach this frontier: now let's see what is promised by our exploration.

An issue study completed by the Coast Guard in March of this year outlined in some detail just what the future will bring as we move to implement vessel traffic control systems around the nation. First, a phased development approach is being utilized to gain the experience necessary to effectively implement control systems. This is similar to an explorer setting up a base camp in order to establish himself in unfamiliar territory before pushing on. Vessel traffic control systems can be effectively divided into various levels of control, from the passive form of mere radar surveillance to actively permitting or forbidding the movement of vessels in certain circumstances. Consequently, the establishment of vessel traffic systems will progress cautiously. Only after experience is gained at the initial stages of implementation will more active controls be considered.

In San Francisco, for example, an experimental vessel control system has been operating since the fall of 1972. Control there has to date progressed from radar surveillance to a voluntary separation scheme to the publication of voluntary guidelines in the Federal Register.

The Puget Sound control operation is another example of this systematic approach. After careful study of that area's particular problems, a voluntary vessel movement reporting system and traffic separation scheme were instituted in June 1972. Since that time the operation has undergone further revision and in late August a public hearing was held on prpposed rules that would make the present system mandatory. At every juncture enough experience had been gained to warrant carrying the system one step further, and this procedure will be followed in other ports.

Both these pilot programs proved to be an invaluable testing ground for both the techniques and equipment of effective, practical control. Just as important, the implementation of these two systems was very encouraging from a regulatory standpoint in that a cooperative spirit grew between the local maritime interests affected and the government representatives who were designing the system. Every effort was made to enlist the support and assistance of the people who would be affected by vessel controls, and this method will be repeated as we move to implement VTS in other ports.

The other ports now under consideration for vessel traffic control systems are the Houston/Galveston ship channel, New Orleans, Valdez, Alaska, and New York. For the Houston/Galveston area a combination of a vessel movement reporting system, radar surveillance, and television coverage of critical areas is planned. The system planning is complete, and construction has already begun. It is hoped that the system will be operational next year.

Plans for the New York and New Orleans systems are on the boards and money has been allocated for the initial stages of development. Just last week an open meeting of the advisory committee established by the Coast Guard for consultation on the New York Harbor system discussed the ramifications of the project in a day long session.

The years ahead will bring the gradual completion of vessel traffic systems in each of these major ports. Further expansion of VTS will be based on a list of "priority ports", which will be determined with the help of a formula devised by a consulting firm. The formula takes into account such factors as vessel damage, pollution incident rate, damage to property, and lives lost to determine if a vessel traffic system should be considered for that particular port. The area under consideration is then analyzed on a casualty by casualty basis to determine if a vessel traffic system could improve navigational safety. This combination of empirical data and subjective analysis will result in a list to be used in planning more extensive implementation of VTS, and it will give us some idea of the benefits to be gained by VTS installation.

A recently completed analysis of New York Harbor using the method I have just described projected an annual reduction in vessel, cargo, and property losses of $1.44 million dollars. This in itself exceeds the annual costs of the system and does not take into account other benefits. Among the other benefits not so easily quantified are reductions in personnel casualties and pollution. We also expect to see reduced operating losses caused by vessels under repair, and reduced operating costs as a result of better planned vessel movements. These, then, are the bright promises of VTS.

At the outset of this speech I noted that the two defining elements of a frontier are accomplishment and promise. We have seen the advances that have been made toward the implementation of vessel traffic systems in major ports around the nation and we have discussed the benefits to be gained as the systems grow. We are committed to the continual review and improvement of the systems now operating, as well as expanding into areas where a definite need is indicated. In this way, by progress steady and sure, we will be continually advancing this new frontier of navigational safety.

# THE NAV-AID: A CALCULATOR FOR NAVIGATION

by

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and

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ABSTRACT

A description is given of a proposed versatile navigator's aid (NAV-AID) made possible by recent advances in calculator technology. The NAV-AID is a portable microdigital computer which, when used with The Nautical Almanac, solves Celestial, Loran and Omega position fixing problems. Additionally, the NAV-AID contains a Deduced Reckoning computer as well as the capability to perform a variety of standard piloting techniques. Subroutines enable the navigator to calculate useful course line parameters and to handle sextant altitude and Omega skywave corrections. Other course and fix-related quantities are accessible through an Auxiliary Data Mode. An Inverse Mode allows Celestial, Loran and Omega data to be predicted, and a Calculator Mode aids in external computations. Anticipated specifications are given.

## INTRODUCTION

For centuries the navigator has been burdened with the laborious task of solving the plane and spherical trigonometry problems associated with the art/science of navigation. These are calculations which, of their nature, are well-defined, exacting, generally convergent, and, most important, very repetitive. There are many different problems whose outward appearances hide their basic mathematical similarity or computational sameness. In short, most of the calculations which fall to the navigator are ideally suited to straightforward computer formulation and solution.

Many ships have on-board mini-computers which handle the complete navigational problem. These machines normally receive input data from external equipment by automated techniques. The NAV-AID (Figure 1) is a proposed, advanced technology, digital computer that is pre-programmed to solve many of the common navigation problems. It receives input manually by way of a calculator keyboard. The NAV-AID is not intended to be a replacement for existing shipboard computers. Rather it is an AID to the Navigator which provides him with personal computer power that is always accessible. The NAV-AID is not a part of a real-time navigational control system. It is portable, battery powered, and lightweight. It can greatly increase the speed and efficiency which the navigator brings to bear on his tasks of planning, piloting and position fixing.

Tremendous innovations in micro-circuitry, displays and miniaturization have provided an enhanced sophistication in the capabilities for programming and data storage in mini-calculators while simultaneously lowering costs significantly. The NAV-AID employs this state-of-the art technology specifically to solve navigational problems.

## GENERAL OVERVIEW OF CAPABILITIES

When used with The Nautical Almanac, the NAV-AID solves all of the important problems associated with position determination for Celestial, Loran and Omega navigation (Table 1). Additionally, it provides the navigator with a means of automatically updating an on-going deduced reckoning (DR) position with data obtained from radio bearings, distance measurements, visual bearings or a combination of these methods.

Internal programming easily accomplishes point-to-point navigation by fixing the course to be made good and then providing steering information in the form of ship's heading, course line deviation, range and bearing to destination, ship's speed (surface and true) and estimated time to arrival.

A crystal oscillator clock in the NAV-AID may be set to GMT and is used both in Celestial and Omega navigation, as well as to provide the time base for constant on-going DR calculations.

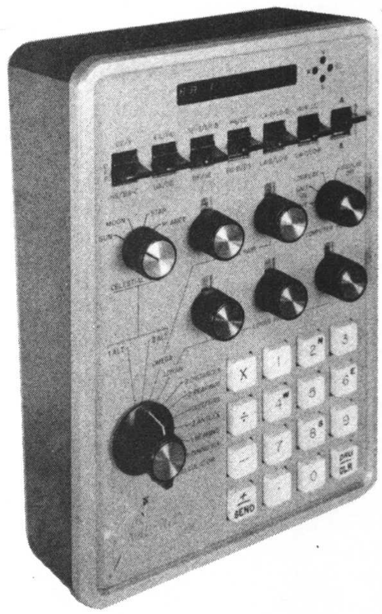

FIGURE 1. MOCK-UP OF NAV-AID

POSITION FIXING (10 METHODS INCLUDING CELESTIAL, LORAN AND OMEGA)
COURSE LINE INFORMATION
- DEVIATION
- RANGE AND BEARING TO DESTINATION
- HEADING TO STEER

CRYSTAL OSCILLATOR CLOCK
DEDUCED RECKONING COMPUTER
OMEGA DIURNAL SKYWAVE CORRECTIONS
SEXTANT ALTITUDE CORRECTIONS
AUXILIARY DATA MODES (ADDITIONAL NAV. PARAMETERS)
INVERSE SOLUTION MODES (CELESTIAL, LORAN, OMEGA)
CALCULATOR MODE
LIGHTWEIGHT, PORTABLE, BATTERY POWERED

TABLE 1. GENERAL NAV-AID FEATURES SUMMARIZED

Permanently programmed in the NAV-AID are subroutines which calculate Omega diurnal skywave corrections and various standard sextant altitude corrections, thus eliminating the need for cumbersome tables, with a sizeable reduction in the time required for position fixing using these methods. Trig function capability replaces the tedious use of tables and tabulated spherical triangle solutions.

Two other significant and innovative features are the Auxiliary and Inverse Data Modes. The first is an internal routine which automatically calculates additional information relevant to each of the various position fixing methods and presents these data sequentially upon operator request. The Inverse Mode has the capability to solve three inverse problems associated with Celestial, Loran and Omega navigation; namely, prediction of the expected input data for each of these methods based on the calculated DR position. For example, this mode is employed to predict the approximate sextant altitude of a star to aid in finding it under overcast conditions. It is also used to forecast Omega lane counts to remove possible ambiguities at 10.2 kHz.

Finally, the NAV-AID contains a standard four-function (+ - x ÷) calculator to expedite the preparation of certain data for entry into the NAV-AID or for performing calculations other than those already stored inside.

The NAV-AID is compact, battery or line powered, and above all convenient, quick and easy to operate. The general technique in using the NAV-AID is to select a particular fixing mode or piloting method using the switches provided and then to press the DRU/CLR (Deduced Reckoning Update/Clear) key. This initiates an automatic computer sequence which literally tells the navigator the data it requires by means of a coded display. As the requested data is entered, it is automatically stored and then processed to give the desired position fix or other relevant information. Any stored parameter can be recalled, displayed or changed by using the appropriate switches and the keyboard. At each position fix, the DR track is forced to intersect the actual track, while between fixes the vessel's present position is updated by continual DR.

## COURSE LINE PARAMETER CALCULATIONS

The navigator establishes the course to be made good (Figure 2) by keying in the LAT/LONG of the starting point, the present position, and final-point. If magnetic variation corrections are desired, the values for these are entered for the course line end-points. (Magnetic deviation values for the vessel can be permanently stored in the machine).

ENTER

FINAL POINT COORDINATES
STARTING POINT COORDINATES
PRESENT POSITION COORDINATES

NAV-AID COMPUTES

ANGLE A - BEARING TO FINAL POINT
DISTANCE $D_1$ - DISTANCE TO FINAL POINT
DISTANCE $D_2$ - COURSE LINE DEVIATION

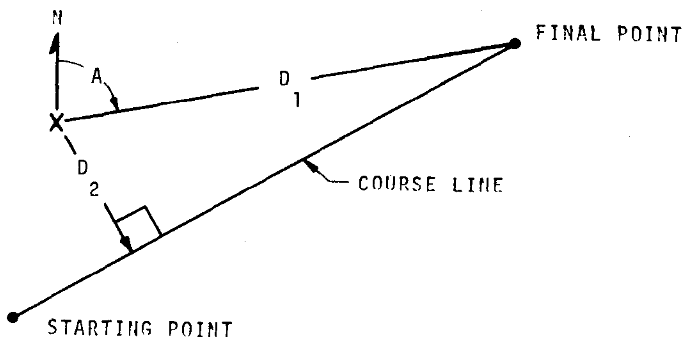


FIGURE 2. ESTABLISHING THE COURSE LINE

The drift and set of the current are then entered using the appropriate parameter switches. This sequence establishes the course line to be used as a reference in all future calculations (Figure 3). The NAV-AID now calculates range and bearing to the final point and more importantly, with the vessel's surface speed, the correct heading to steer for a great circle course to the destination.

ENTER:

SURFACE SPEED
DRIFT AND SET OF CURRENT

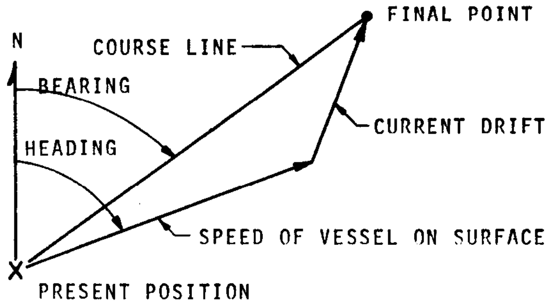


FIGURE 3. HEADING COMPUTATION

When a non-zero value of the ship's surface speed is entered, internal automatic DR is also immediately initiated (Figure 4). The user may monitor any parameter as the NAV-AID performs DR. Changing quantities, such as the present position, are updated approximately every 10 seconds. Any parameter may be changed at will merely by keying in a new value.

INFORMATION PROCESSED

SURFACE SPEED
HEADING
DRIFT AND SET OF CURRENT
STARTING POINT COORDINATES

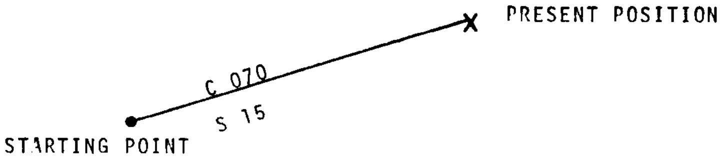


FIGURE 4. AN ON-GOING DR COMPUTER

As time progresses and position fixes are obtained to update the DR, the NAV-AID automatically computes various additional quantities relevant to the course line. These include course line deviation (distance of actual course from course to be made good), track angle (angle of actual course measured from True North), track angle error (angular deviation of actual course from desired course), true "ground" speed of vessel, and new range and bearing to destination.

POSITION FIXING AND PILOTING TECHNIQUES

Permanently stored in the NAV-AID are ten routines for obtaining a position fix, along with two other methods for updating the DR position when there are insufficient data to perform a complete fix. These are shown in TABLE 2.

| LINE OF POSITION METHODS: | POSITION FIXING METHODS | |
|---|---|---|
| ONE BEARING | RUNNING FIX | TWO BEARINGS |
| CELESTIAL ALTITUDE | LORAN (A OR C OR MIX OF A AND C) | TWO CELESTIAL ALTITUDES |
| | OMEGA | DISTANCE AND BEARING |
| | LORAN/OMEGA COMBINATION | TWO HORIZONTAL ANGLES |
| | DIRECT POSITION | TWO DISTANCES |

TABLE 2. POSITION UP-DATE METHODS

In general, the navigator first determines what information he has at his disposal, what methods of position fixing he can perform, and which technique is likely to be the most accurate, depending on which data are the most reliable. He then simply initiates the automatic request sequence and enters the appropriate data. When the last parameter is input, the NAV-AID calculates the present geographic coordinates, updates the DR track and changes any other position-related quantity (range and bearing to destination, estimated time to arrival, etc.). Three specific examples should clarify NAV-AID operation and demonstrate computational capabilities.

SINGLE CELESTIAL ALTITUDE LOP

A single sextant reading provides sufficient information to determine a line of position and update the DR position. The NAV-AID greatly simplifies celestial navigation by automatically performing the standard sextant altitude corrections for dip (height-of-eye), parallax, semi-diameter (sun, moon) and refraction. Other lesser corrections (e.g. wave-height, tilt, sea-air temperature difference, etc.) may be quickly computed if necessary using the Calculator Mode. The values of the corrections automatically performed, and other pertinent data, may be obtained following the DR update using the Auxiliary Mode described below. The Calculator Mode is also employed in Celestial Navigation to find the Greenwich Hour Angle (GHA) of the celestial body using information supplied by the Daily Page of The Nautical Almanac.

Upon receipt of these data the NAV-AID updates the DR position P to the closest point located on the line of position (LOP) determined from the geographic position (GP) of the observed celestial body (Figure 5). The user may now access the Auxiliary Mode to display information relevant to this "fix", such as range to GP and the sextant altitude corrections, if he wishes to check these quantities.

| DISPLAY CODE | ENTER |
|---|---|
| SL C | SELECT CELESTIAL BODY (SUN, MOON, STAR, PLANET) |
| HA 1 | GHA OF SIGHTED OBJECT |
| DC 1 | DECLINATION OF OBJECT |
| HS 1 | SEXTANT ALTITUDE |
| HE 1 | OBSERVER'S HEIGHT-OF-EYE ABOVE SEA LEVEL |
| HU 1 | GMT AT SIGHTING TIME |

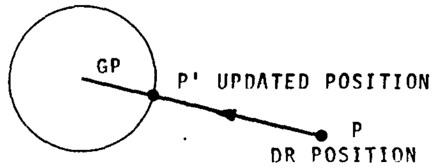


FIGURE 5. ONE CELESTIAL ALTITUDE POSITION UPDATE

## TWO HORIZONTAL ANGLE POSITION FIX

A fix may be obtained by means of the difference in bearing of several sighted objects. This is generally a very accurate method because constant instrumental errors which may exist tend to be cancelled by the nature of the fix. Usually two angles are obtained from three visually (or electronically) sighted objects as illustrated in Figure 6. If the three objects chosen lie on, or approximately on, a circle which also includes the present position of the vessel, the method fails. (The Resolver Problem - more on this in the Auxiliary Mode discussion below.) Figure 6 also shows the NAV-AID data request sequence and action following input.

| DISPLAY CODE | ENTER |
|---|---|
| LA 1 | LAT. OF OBJECT SIGHTED AT 1 |
| LO 1 | LONG. OF OBJECT SIGHTED AT 1 |
| AL 1 | ANGLE BETWEEN 1 AND 2 |
| LA 2 | LAT. OF OBJECT SIGHTED AT 2 |
| LO 2 | LONG. OF OBJECT SIGHTED AT 2 |
| AL 2 | ANGLE BETWEEN 2 AND 3 |
| LA 3 | LAT. OF OBJECT SIGHTED AT 3 |
| LO 3 | LONG. OF OBJECT SIGHTED AT 3 |

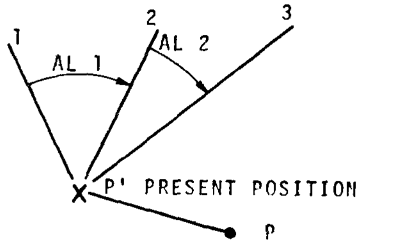


FIGURE 6. TWO HORIZONTAL ANGLE FIX

When the above data are received the NAV-AID calculates the present position P' and updates the DR position P immediately. Internal checks are performed to determine whether the three sighted objects and the vessel all lie on the same circle. The NAV-AID informs the user of potential failure of the method by displaying the resolver angles in the Auxiliary Mode. Graphically, a navigator performs this method using the cumbersome three-arm protractor. The NAV-AID provides accuracy at least as good as the graphical method in a minute fraction of the time.

## LORAN POSITION FIX

The procedure for obtaining a position fix using Loran is extremely simplified over conventional methods since the coordinates of all Loran A and C transmitters are permanently stored in the NAV-AID. The use of charts to determine Loran fixes is no longer necessary and thus the average time to perform a fix is reduced drastically. An added convenience is the NAV-AID's ability to mix Loran A and Loran C to perform a fix when neither has two sufficiently reliable rates available. The NAV-AID algorithms do not distinguish between the two since both are essentially the same hyperbolic method. Figure 7 shows the display sequence which occurs when the Loran fix is initiated.

| DISPLAY CODE | INSTRUCTIONS |
|---|---|
| SL L | SELECT LORAN RATE USING THE DIAL SWITCHES TO DESIGNATE ONE OF THE POSSIBLE LORAN A OR C MASTER-SLAVE PAIRS |
| YS 1 | ENTER LORAN TIME DIFFERENCE IN MICROSECONDS |
| SL 1 | SELECT SECOND LORAN RATE |
| YS 2 | ENTER SECOND MEASURED TIME DIFFERENCE |

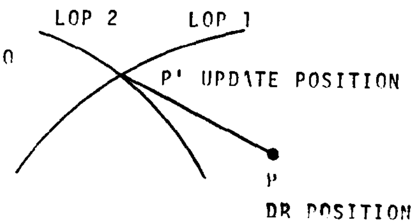


FIGURE 7. LORAN FIX

Upon receipt of the two differences, the NAV-AID computes the fix and updates the DR position. The Loran sequence automatically calculates the crossing angle of the two hyperbolic LOPs to inform the user in the Auxiliary mode of a possibly unreliable fix at very small angles. Also determined here are range and bearing to the Loran pairs so the user may avoid being on a base-line extension. (Note also that, in addition to pure Omega fixes, the NAV-AID can combine hyperbolic lines of position from both Omega and Loran to obtain a position fix.)

## THE AUXILIARY MODES

As noted above the NAV-AID has been programmed to calculate certain data which are auxiliary to each DR update method. In addition, other information which is independent of the DR update mode is continually being calculated and stored in the Auxiliary Data Modes. It is accessible through the AUX 1/2 parameter switch.

AUX 1 contains independent heading information in the form of track angle, track angle error and time elapsed since the last DR update. These parameters are continually updated whether or not a fix is performed. Other quantities relevant to the course are accessible directly and individually through use of the parameter switches as described in Section II.

AUX 2 contains information relevant to the latest DR update. Quantities such as crossing angles of LOPs, distances to sighted objects, sextant corrections, Omega skywave corrections, speed errors, and resolver angles are calculated and stored in AUX 2 depending on which fixing technique the NAV-AID performed.

Figure 8 illustrates the use of AUX 2 in connection with the Two Horizontal Angle Fix discussed above. It was noted that this method fails if the three sighted objects and the vessel all lie on the same circle. When the requested data are input, AUX 2 determines the circle of ambiguity by computing the radius of the circle and locating the center of the circle by specifying the two Resolver Angles. (It is common knowledge that the resolver problem can be eliminated by choosing objects so widely separated that the angle between the outermost is approximately 180°, by choosing objects nearly colinear, or by selecting a group of objects with the center one nearer than the other two.) AUX 2 supplies the observer's range to each object and the vessel's speed error on the bottom (SP E). This parameter is the difference between speed on the bottom as computed from operator inserted parameters and measured data obtained from time and position fix information.

AUX CALCULATED PARAMETERS

DISTANCES TO 1, 2, 3, 4 FROM P
RESOLVER ANGLES
SPEED ERROR ON BOTTOM

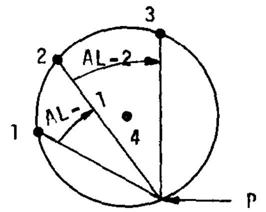


FIGURE 8. CIRCLE OF FIX AMBIGUITIES ASSOCIATED WITH THE TWO HORIZONTAL ANGLE FIX (THE RESOLVER PROBLEM)

## THE INVERSE MODES

A very convenient feature of the NAV-AID is its ability to solve inverse problems associated with Loran, Omega and Celestial navigation. The NAV-AID is programmed to work from the present DR position backwards to predict time difference or cycle-count data to be expected in performing a measurement of given Loran or Omega signals. In the inverse celestial problem the NAV-AID will predict the sextant altitude of a given celestial body along with its magnetic bearing. The data provided by this mode can thus prove very valuable to the navigator in making his subsequent choice of DR update method or simply in speeding up a celestial fix by knowing approximately where to look for a particular star. The input request sequence for the inverse celestial problem is illustrated in Table 3.

| DISPLAY CODE | INSTRUCTIONS |
|---|---|
| SL C | SELECT CELESTIAL BODY using APPROPRIATE SWITCH |
| DC 1 | ENTER DECLINATION OF BODY OBTAINED FROM NAUTICAL ALMANAC |
| HA 1 | ENTER GHA OF CELESTIAL BODY |
| HE | ENTER SEXTANT ELEVATION ABOVE SEA-LEVEL |
| HU | ENTER GMT OBTAINED FROM NAV-AID CLOCK |
| HS | HS PARAMETER SWITCH NOW DISPLAYS PREDICTED SEXTANT ALTITUDE |
| BG | BG C PARAMETER SWITCH DISPLAYS MAGNETIC BEARING TO CELESTIAL BODY'S GP |

TABLE 3. PREDICTION OF SEXTANT ALTITUDE AND BEARING OF A CELESTIAL BODY (CELESTIAL INVERSE PROBLEM)

The information resulting from the solution of the inverse problem is automatically corrected for dip and refraction. The NAV-AID is therefore predicting the approximate reading of the sextant for the chosen celestial body.

There are two obvious uses for the data provided by the solutions of the inverse Loran and Omega problems. These arise in situations where only a single Loran time difference signal or Omega cycle count is available. In these cases it is possible to update the DR position first by obtaining a predicted time difference or cycle count and by then using this with the hard data actually available to perform a Loran or Omega fix. The reliability of a fix obtained in this manner is strongly dependent on the accuracy of the DR position and should be checked carefully. The results may be less precise than the original DR position, especially if the crossing angle of the two LOPs is small.

Additionally the inverse problem solving capability will normally enable the navigator to resolve Omega lane ambiguities by predicting the skywave-corrected cycle count at 10.2 kHz.

## CALCULATOR MODE AND ERROR MESSAGES

In the Calculator Mode the NAV-AID becomes a standard four function, eight-digit arithmetic calculator (Table 4.)

It may thus be used in preparing fix data for input and for performing various conversions, linear interpolations, or other numerical computations. Employing the accumulator as a storage register one may easily perform chain arithmetic operations. A numerical overflow of the accumulator results in the blinking error message EE 0.

| CHAIN OPERATIONS USING THE ACCUMULATOR | |
|---|---|
| ADD | MULTIPLY |
| SUBTRACT | DIVIDE |

TABLE 4. THE CALCULATOR MODE

The NAV-AID is programmed to detect other possible errors or problems. Formatting errors (entering too many or too few digits) are signalled by a blinking EE F. Impossible situations, where data input to determine a heading or other quantity lead to no solution, are indicated by the message EE 1. The condition of marginal battery voltage is displayed to the operator by a flashing EE 2.

## PERFORMANCE AND SPECIFICATIONS

Table 5 illustrates liberally anticipated maximum errors of selected NAV-AID functions and subroutines.

| COMPUTATION | MAX ERROR |
|---|---|
| POSITION FIX | |
| OMEGA | 2.5 NAUTICAL MILES |
| ALL OTHER METHODS | 0.5 NAUTICAL MILES |
| DISTANCE | 0.3 NAUTICAL MILES |
| HEADING | 0.3 DEGREES |
| INVERSE PROBLEM | |
| CYCLE COUNT (OMEGA) | 20 CENTICYCLES @ 10.2 KHZ |
| TIME DIFFERENCE (LORAN) | 2 MICROSECONDS |
| SEXTANT ALTITUDE (CELESTIAL) | 5 MINUTES |
| BEARING ANGLE (CELESTIAL) | 1 DEGREE |

TABLE 5. NAV-AID ACCURACY

Position fixing accuracies are based on 75 percent of total measured events and on LOP crossing angles greater than 15 degrees. Distance precision holds up to 10,000 nautical miles due to the use of non-spherical earth correction algorithms permanently stored in the NAV-AID. Accuracy of Omega is obtained by using the Pierce diurnal skywave correction model modified to include a surface conductivity correction.

Typical solution times are illustrated in Table 6. Physical characteristics are given in Table 7.

All of the features and capabilities discussed above combine to create an exceptionally powerful and useful navigational tool. The reduction in time over conventional graphical fixing and piloting methods is obviously significant and can only lead to greater security for the vessel and its crew. Operation is simple, logical and easily mastered because much effort has been directed to follow common navigational formats and principles. There is little doubt that a machine such as this will revolutionize the navigator's old business of getting his vessel safely from Here to There.

| SUBROUTINE | MAX SOLUTION TIME |
|---|---|
| LORAN POSITION FIX | 10 SECONDS |
| OMEGA DIURNAL CORRECTIONS | 25 SECONDS |
| RANGE COMPUTATION | .8 SECONDS |

TABLE 6. TYPICAL SUBROUTINE SOLUTION TIMES

SIZE 8" X 6" X 2"
WEIGHT 3 LBS.
BATTERY LIFE
- CONTINUOUS 2 HOURS
- DR MODE 2 WEEKS

TEMPERATURE RANGE
- STORAGE - 20°C TO +60°C
- OPERATING 0°C TO +50°C

BATTERY CHARGER LOCATED EXTERNAL TO THE NAV-AID (BATTERY CHARGER DESIGNED TO FUNCTION FROM EITHER ALTERNATING OR DIRECT CURRENT VOLTAGE SOURCES)

TABLE 7. PHYSICAL CHARACTERISTICS


## ACKNOWLEDGEMENT

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MARINE INSTRUMENTATION DEVELOPMENTS

by

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ABSTRACT

The National Maritime Research Center, Kings Point, N. Y., is conducting projects dealing with the "new technology" in the field of navigation. This paper consists of a survey of this area of activity of the Center. The intent is not only to disseminate information to the wide community of navigators but also to structure a mutually beneficial communications link between the NMRC and the Institute of Navigation. The paper will cover the following projects, some innovative, others extensions of previous programs:

- RAPS (Radar Automatic Plotting System)
- MASS (MarAd Anti-Stranding Sonar)
- TRANSIM (Simplified Transit)
- MARINE RADAR TRANSPONDER
- MARSCAN (Maritime Satellites Communication and Navigation System)
- INTEGRATED CONNING SYSTEM

INTRODUCTION

The Woods Hole Conference on Maritime Research and Development held in 1969 and sponsored by the Maritime Administration set the scene for the maritime program of the 70's and beyond. Some two-hundred experts from various maritime interests and disciplines convened to formulate such a program. This group prepared over one hundred "problem elements" which, in the main, have served as guidelines for a vigorous program in marine science and technology and in marine operations and economics.

A primary concern of the Maritime Administration is the "increased productivity of the U. S. Merchant Marine". The conference concluded that this goal could be attained to a great extent by applying the state-of-the-art advances in technology, many reflecting defense and aerospace activities, to the business of ship construction and operation. The establishment of the National Maritime Research Centers at Kings Point and at Galveston gave further credence to this approach.

The systems to be described have been completed or are in continuing phases of development. In each instance it is hoped that the system will contribute to the safer and more economical operation of U. S. merchant ships.

RAPS (Radar Automatic Plotting System)

A joint study and development effort by the NMRC, Kings Point, and ITT-Gilfillan culminated in a simple shipboard video aid for automatic radar plotting. The goal was to achieve a low-cost but effective system in the area of collision avoidance for ships having the availability of a minicomputer. A likely candidate ship would be one having a Transit installation utilizing such a computer. For ships having such a capability, RAPS provides, at modest cost, semi-automatic collision avoidance techniques which would otherwise be available only at high cost through some of the more automatic, sophisticated systems.

Under its present format, the RAPS system is limited to the manual acquisition (two sets of bearings and ranges as keyboard inputs) of up to ten targets. In dense traffic situations, the watch officer must select those ten targets he deems most urgent to display. Once two sets of data are entered for any target, the RAPS will calculate and display the CPA and time, the course and speed of each target, and the STATUS (Danger or Safe) as predicated on an input Buffer Zone. The watch officer can also simulate maneuvers to avoid possible collision. All data entered as well as the prediction results are presented on the display as shown in Figure 1. The items with dotted underlines are automatically written by the program as part of the initialization. The items with solid underlines are results which are automatically written by the program. The remaining items are entered by the watch officer. Figure 2 shows a simplified flow chart of the operational procedure for using the RAPS equipment.

The present configuration of the RAPS consists of an alpha-numeric display and keyboard (Hazeltine 2000) and a fast data interface located in a DEC PDP-8e computer to provide adequate display response time. The computer program is completely contained in 4K of memory and can be loaded into the computer via a teletype tape reader.

As presently implemented, the computer has 8K of memory, 4 of which is used for the Transit (SATNAV) requirements. The watch officer calls up the desired program (RAPS or SATNAV) via the computer front panel switches. He then follows simplified operating instructions which are mounted on the display unit next to the display for easy access.

The design objectives for an operational RAPS have been resolved as follows:

- To provide an effective means for handling complex traffic problems on the bridge of a merchant ship.

- To allow rapid determination of a collision avoidance maneuver involving up to ten ships of immediate concern.

- To retain the human element in control of the system and in the selection of the ships (targets) of immediate concern while requiring little more activity than the normal radar scope monitoring.

- To keep the system simple, and therefore reliable and easy to operate.

- To keep the system cost at a level which is compatible with the fiscal requirements of the majority of ships.

MASS (Maritime Anti-Stranding Sonar System)

Statistically, strandings occur in greater frequency for ocean going vessels than collisions. In these instances, the cost of repairs and loss of revenue due to out-of-service time is sometimes further complicated by the pollution of the seas by oil.

It is hoped that the incidence of such strandings will reduce drastically through the use of MASS, a system developed by Raytheon under sponsorship of the Office of Research and Development of the Maritime Administration. Phase II, recently completed, consisted of successful test periods on Raytheon's MV SUB SIG and on Kings Point's RV KINGS POINTER. Phase III is presently going on with a prototype being tested on the SS DELNORTE, a LASH type ship of the Delta Steamship Company, making the run between the Gulf Coast and the East Coast of South America.

The MASS consists of a small shipboard sonar system that will alarm the presence of bottom conditions and obstacles below the surface that are potentially dangerous to a ship's safe passage. It is particularly suited to vessels of deep draft or to vessels navigating where bottom conditions are predictably changeable. It could also be of great value to vessels navigating in poorly charted areas or to ships proceeding through narrow channels.

The system directs narrow acoustic beams from hull-mounted transducers downward and ahead of the ship as shown in Figure 3. The downward-looking beam is used to measure the depth and to estimate (predict) a distance to stranding based on the average slope of the bottom. The forward-looking beam detects, in advance of the ship, the presence of obstacles such as rocks, wrecks, and sand bars, which have depths less than keel depth. Characteristic of ship's draft, speed, and turning circle (see Figure 4) are utilized in the bridge mounted display to provide advance alarm and thus permit early action to avoid the dangerous situation.

Stacked echoes are utilized to alarm, rather than a single echo, which greatly reduces the possibility of false alarms. In Figure 3 a target is being displayed at 1200 meters with the beach displayed 300 meters later at 1500 meters. The dotted diagonal line indicates the placement of an alarm level adjusted to ship characteristics. The 1200 meter target having stacked to the alarm level is in the alarm condition.

The stranding estimator functions from a series of echoes which are used to compute bottom slope. Estimated stranding distance is displayed. Ship characteristics are entered into the stranding estimator to establish the threshold for alarm. Depth alarm is also actuated by the bottom echoes with threshold adjustable to ship's draft and trim characteristics.

As shown in Figure 5, the system consists of a small transducer array mounted on or near the ship's forefoot, an unattended equipment rack for the acoustic transmitter and receiver, and the bridge mounted display and alarm indicators.

A parametric sonar is used to generate the required narrow forward-looking acoustic beam at a low frequency with a reasonably small transducer. The transducer simultaneously transmits 189.5kHz and 210.5kHz signals. The two signals are mixed by nonlinear effects in the water to produce a 21kHz signal with a beam pattern which is essentially the same as the beam pattern of either high frequency signal.

A correlation processor is used to minimize false alarm in the forward-looking sonar. This processor generates a swept frequency tone burst which is transmitted into the water by the transducer and stored in a register within the processor. The stored frequency signature is continually compared with the signature of the signals at the receiving transducer. Only echoes of the transmiited signal will correlate and give an output; background noise is random in nature and will not correlate.

Obstacle identification calls for the accumulation of echoes from several transmissions. The display range is divided into many bins. A bin is actually a word in memory containing the number of accumulated echoes at that range. After each transmission, the processed echoes above a pre-set threshold cause the stored numbers in their respective bins to be incremented. The number in each bin is displayed on the CRT, as the length of a line at the respective position on the range axis. A display manual reset is provided to clear the display and start over if a large course change is made.

The ship's speed input causes the "Bar Graph" to move across the screen, correcting the actual range to a stationary target which is decreasing as the ship moves forward. Fixed obstacles appear as bars which grow and move across the screen. Moving targets such as fish, and background noise fill different bins each time and thus do not produce any noticeable bar. Accurate inputs of ship speed are necessary for the display to correctly compensate for ship's forward motion. To fulfill this requirement the system includes a doppler log subsystem.

When there is no operational concern over obstacles or stranding, the system can be utilized only as a speed log and depth sounder.

TRANSIM (Simplified Transit) (Low-Cost Navy Navigation Satellite System)

The TRANSIM system was developed at the Applied Physics Laboratory of the Johns Hopkins University under Navy sponsorship to meet the need for a low-cost, simplified, moderately accurate version of the more expensive operational Navy Satellite Navigation System (TRANSIT).

The set design goals were that: the complete system must cost less than $10,000; fixed site navigation accuracy be less than one nautical mile; no significant reduction in receiver sensitivity; system shall operate in 0° to 60°C temperature range; design of receiver be conducive to easy construction, maintenance and operation; design computational routines be such as to minimize operator training and maximize ease of use.

The system was loaned by the U.S. Navy to the Maritime Administration for the purpose of conducting a joint evaluation with the Applied Physics Laboratory to confirm its suitability to fulfill the global high seas navigation requirements of the U.S. Merchant Marine.

During this evaluation, from March through December 1972, the system was evaluated first at the U.S. Merchant Marine Academy and then on three different ships:

- the RV NEREID, a research and training vessel based at the USMMA;
- the SS ERIC K. HOLZER, a roll-on roll-off ship in service between New York and Puerto Rico, and;
- the SS AFRICAN METEOR, a break-bulk cargo ship in service between the Eastern United States and Australia and Africa.

The system consists of (1) a receiver designed and built by the Applied Physics Laboratory (see Figure 6.), (2) a programmable electronic calculator commercially available from the Wang Laboratories, Inc., and (3) a receiving antenna manufactured by Chu Associates. The navigation programs for the calculator were written by the Laboratory personnel. Figure 7. shows a block diagram of the system.

Most of the data collected was accumulated during voyages on the SS AFRICAN METEOR which lasted nearly five months. One of the main objectives of the TRANSIM evaluation, to determine its operability by typical merchant-ship deck officers, was considered to have been successfully accomplished. This stress on operability was due to the fact that this system is not a totally automatic system as the other systems. This feature is a contributing factor to the low cost of the system.

It was felt that this system provided fixes in areas where only celestial fixes had been previously available. Also, the deck officers experienced minimum difficulty in mastering its operation. An additional advantage of the system was felt to be the use of the multi-purpose calculator. This calculator is capable of handling computations on stability, trim, fuel consumption, payrolls and other shipboard requirements. On the SS AFRICAN METEOR both Great Circle and Mercator Sailings problems were computed on this calculator.

MARINE RADAR TRANSPONDER

The Maritime Administration in conjunction with Sperry Marine Systems Division of the Sperry Rand Corporation is presently involved in the second phase of the development of a marine radar transponder system. The purpose of such a system is to improve the safety of navigation by the reduction of collisions and strandings. In this guise, the system can be considered to be a secondary radar system intended to improve and supplement the effectiveness of the primary radar system. For large ships it is not meant to replace the present radar system. The objective of the project is to develop a system which could be internationally adopted and which could provide a family of devices of various degrees of complexity to the user, according to his needs, to accomplish the following:

- Target Enhancement - to improve the target response from all equipped vessels whose magnitude is independent of target size and which can be displayed independently of sea, rain, or land clutter.
- Target Identification - ability to associate a name such as call letters of a new code with a response on the PPI without prior knowledge of its identity and then to be able to selectively address it for subsequent communications.
- Selective Calling - for the automatic interchange of information between ships and between ships and shore.
- Communications - ability to transmit messages over this link in a manner independent of the language barrier.

The principal device in the system is the Interrogator-transponder which is designed for use in conjunction with a shipborne or shore-based radar or by itself. A simple block diagram of such a transponder is shown in Figure 8.

## MARSCAN

Since 1970, the Maritime Administration has been engaged in an experimental program designed to provide improved communications and navigation to ships at sea via satellites. The project is being conducted in conjunction with AII Systems, and the NASA. Its main features will be only briefly outlined here, since several papers have already been presented on this program.

The system configuration is modeled after an operational system concept which was developed during the first phase of the program. This concept, as shown in Figure 9, reflects a system of synchronous equatorial satellites linking ships to shore Maritime Coordination Centers and providing maritime communication and navigation capability to all parts of the world with the exception of polar regions above approximately 75° latitude.

The Maritime Coordination Center is designed to function also as a switching center for linking the ships with their home office so that expeditious management information can be exchanged. One satellite per ocean can accomodate the communications needs; two satellites per ocean would be needed to provide the position of ships by ranging techniques either at the MCC (active mode) or on the ships (passive) or both. The position determination at the MCC provides a "surveillance" capability, important in search and rescue operations. A second satellite per ocean provides redundancy in communications.

The second phase of the program has resulted in experimental system development and operation. The NASA satellites ATS-3 and ATS-5 have been used in conjunction with the Maritime Coordination Center (experimental) at the National Maritime Research Center at Kings Point, N.Y. Figure 10 and 11 portray, respectively, the coverage areas for the satellites and an artist's concept of the MCC. Nine merchant ships of the U.S. Merchant Marine plus the R.V. KINGS POINTER were fitted with experimental ship terminals and antennas. Experiments were conducted both in the Atlantic and in the Pacific.

A recent additional experiment in the project has been to pursue a program of "remote radar signal transmission processing and display". This implies digitizing the radar display and relaying it via satellite link to the MCC where it is computer analyzed and reconstituted and thus contributes to a "satellite-aided collision avoidance system". The experiment involved the R.V. KINGS POINTER and the NMRC's experimental MCC.

## INTEGRATED CONNING SYSTEM

Operational evaluation of the Integrated Conning System has been going on for some time on the C.V. EXPORT FREEDOM of the American Export Lines and Phase I has just been completed. This program is a joint effort of the Maritime Administration, American Export Lines, and Automated Marine International.

The intent of the program was to integrate through a minicomputer several navigation systems and a collision avoidance system so that navigational and collision avoidance solutions would be readily available to the watch officer or master with a minimum of time and manual involvement. A second minicomputer was used as a slave to give computational redundancy in the event of computer failure. Figure 12. is a block diagram of the complete system.

The Modular Bridge concept incorporated in this ICS console reflects a high degree of concern for the human engineering requirements on the bridge of a fast container ship.

EXPERIMENTAL SYSTEM CONFIGURATION

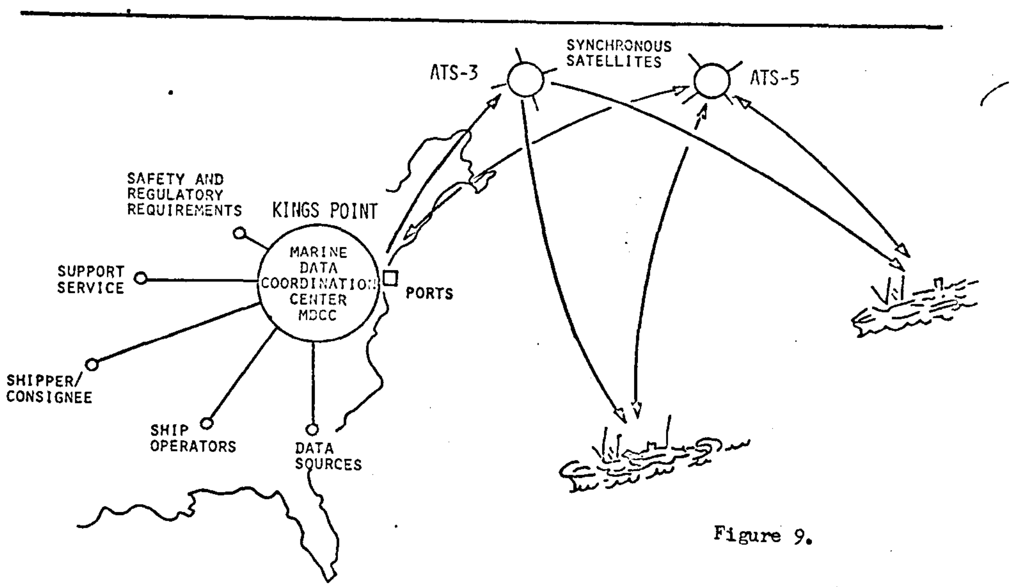


Figure 9.