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RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
TRANSPORTATION SYSTEMS CENTER
CAMBRIDGE, MA 02142

September 19-21, 1978

November 1978
Conference Proceedings

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16. Abstract

A "Conference on Navigation in Transportation" was held at the Transportation Systems Center, Cambridge, Massachusetts on September 19-21, 1978. The underlying theme of the Conference was the current status and utility of civil navigation systems such as VOR/DME, LORAN-C, OMEGA, and GPS (Global Positioning System). Applications of these navigation systems to user groups with diverse requirements - air, marine, and land-based - were addressed.

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PREFACE

The Transportation Systems Center (TSC) at Cambridge, Massachusetts, was the host for the "Conference on Navigation in Transportation", on behalf of its sponsoring agency within the Department of Transportation, the Research and Special Programs Administration (RSPA). Dr. John Fearnsides, Deputy Under Secretary of Transportation opened the Conference with a discussion of navigation issues facing DOT. Dr. James Palmer, Administrator of RSPA, described the role of his Administration with DOT. Twenty-seven papers were delivered on a variety of civil navigation systems addressing the air, marine, and land user community. James Andersen, Director of the Office of Air and Marine Systems at TSC, served as the Conference Chairman and Host.

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Dr. James Costantino, Director
Transportation Systems Center

OPENING REMARKS

CONFERENCE ON NAVIGATION IN TRANSPORTATION

Dr. James Costantino, Director

Transportation Systems Center
Kendall Square
Cambridge, Massachusetts 02142

Good Morning, Ladies and Gentlemen:

Welcome to the Transportation Systems Center and to the Conference on Navigation in Transportation. Each year TSC hosts a great number of conferences and symposia, but few have generated such interest as this one, from so broad a spectrum of the transportation community. Truly, it's a pleasure to welcome you here today. I would also like to extend a special welcome to students present from the nearby universities, for you are the users of the future, and what we will be discussing for the next three days is nothing less than the future of civil navigation.

This conference is sponsored by the recently created Research and Special Programs Administration of the Department of Transportation and has a dual purpose.

First of all, it will allow us to present, <u>for the first time</u>, a comprehensive view of the navigation issues, programs and plans of the Department of Transportation. Speakers from each DOT Administration having a major interest in navigation will outline their programs and indicate how navigation systems affect their mission and responsibilities. In this way, we hope to show how the navigation activities of the several Administrations will merge into a unified departmental navigation program.

A second purpose of the conference is to initiate an active dialogue between the Department and users of civil navigation systems. This technology transfer is part of an expanded effort to foster two-way communication between the Department and the diverse user communities we serve.

We at TSC have been called upon to play an increasingly important role in navigation activities within DOT The Navigation Center recently established here is a key example of our new responsibilities. Through the Navigation Center, TSC hopes to assist the Department by improved planning of navigation systems, assessment of critical technologies and increased communications with you, the users and operators.

To give you an overview of our role here in Cambridge, this Center is DOT's major research analysis and development facility for highway, air, rail,

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SESSION I
NAVIGATION ISSUES FACING DOT

CONFERENCE CHAIRMAN

James Andersen, Director
Office of Air and Marine Systems, TSC

NAVIGATION ISSUES FACING DOT

Dr. John Fearnsides
Deputy Under Secretary of Transportation

NAVIGATION ISSUES FACING DOT

Dr. John Fearnsides

Deputy Under Secretary of Transportation
U.S. Department of Transportation
400 7th Street, S.W.
Washington, D.C. 20590

Good Morning Ladies and Gentlemen:

This conference represents an important step in an entirely new DOT navigation planning process. The Adams Administration in DOT has recognized that civil navigation planning and operation is one of our significant responsiblities and is determined to improve this process. Navigation planning in the past has not been what it should have been, mostly due to lack of high level attention within the Department. I am here this morning to tell you this is no longer the case.

Some of the past inadequacies of DOT planning in this area are undoubtedly the reason for the current atmosphere where new plans and navigation studies are springing up everywhere. We mean to take hold of this issue and discharge our responsibility for civil navigation service in a way that will achieve the very best in government planning that is responsive to user needs and requirements.

That is why we have invited you to this conference to hear our current planning and the new initiatives we have started. In an effort to insure that we are, in fact, responsive to the user community, we are planning another conference, in about six months, where we will be the audience, and you will be invited to express your views of what you will hear from us in the next few days.

The Secretary of Transportation, through U.S. Coast Guard and Federal Aviation Administration Legislation, as incorporated by the DOT Act, is the person responsible for providing civil navigation service to the U.S. user community. As such it is his task to determine that we are providing the required services in the most economical manner for the government and the user community. To do this, and to insure the safety of transportation systems, it is imperative that we:

- Determine the proper set of requirements and the most economical systems to meet these requirements;

- Consider the needs of the user and the cost to the user of the systems provided;

We have now written specific navigation action plans to implement the NPN and spell out our near term planning in detail. These action plans will be covered in detail this afternoon. The DOT action plans are being used to ensure close intermodal coordination in the navigation area in both planning and budgeting.

Our other new initiatives in the navigation field include:

- Formation of a new coordination structure for DOT planning. This includes a new navigation council reporting to the Secretary and a navigation support center here at TSC.

- Closer ties to DOD navigation planning. We are completing a memorandum of understanding with DOD that will lead to much closer coordination and produce a single federal radio navigation plan.

- Creation of a DOT navigation economic planning model. We are going to expand the economic analysis work started by the FAA into an accurate, comprehensive economic planning model to allow us to better assess the tradeoffs for the future.

In summary, DOT has taken a whole new look at navigation services and government planning. I think today and the next two days will inform you fully of where we are, where we are going and what our impression is of your problems. We will be most interested in your response to our efforts and we look forward to your attendance at our next conference.

NAVIGATION ISSUES FACING RSPA

Dr. James Palmer
Administrator
Research and Special Programs Administration

NAVIGATION ISSUES FACING RSPA

Dr. James D. Palmer
Administrator
Research and Special Programs Administration

Good Morning Ladies and Gentlemen:

RSPA is the Research and Special Programs Administration - the newest of the DOT Administrations, formed by Secretary Adams in a recent reorganization of the Office of the Secretary. It is made up of the Transportation Systems Center, the Materials Transportation Bureau and a group we call the Transportation Programs Bureau.

Basically all of the technical and R&D management of the Secretary's staff has been pulled together and made into a new Administration. As the first Administrator of RSPA, one of my high priority tasks is to define our role and the product we produce for the Secretary. One of our more important functions will be to coordinate technical issues that are intermodal in nature, which brings me to our present role in navigation.

(Slide #1) This slide shows the new navigation coordination structure that has been approved by the Secretary and is in the process of being implemented.

The heart of the whole process is the Navigation Council. This Council reports to the Secretary or his designated representative. At this time the Secretary's representative is the Deputy Under Secretary, Dr. Jack Fearnsides. Dr. Fearnsides has a Policy Advisory Group made up of myself and senior Coast Guard and FAA officials. The Council is composed of members from the Coast Guard, FAA and RSPA. Its charter is in preparation, but its general functions will be coordination of DOT's navigation requirements and planning, coordination of navigation planning with other Federal agencies and the providing of information for industry and the user community. The Council has two supporting groups -- one made up of all the other DOT modes who will advise on their navigation and radio location requirements and problems -- and the other, a Navigation Center at TSC. This Navigation Center will conduct economic and systems analyses, make technological and cost assessments of new systems, build and maintain a technical data base on navigation system costs, performance and schedules and provide technology transfer to land location users. This Center will provide us with an intermodal navigation technology base and will be the subject of a later talk.

We have been given the task of pulling together modal navigation planning to insure a cohesive treatment of requirements, systems and user needs in the most economical fashion.

Since this whole process is new in DOT and has just been utilized for the first time in preparation for the FY 80 budget, I will run through it so that you may understand better what the present planning process is and how our planning is being done.

In the Fall of 1977 Navigation Action Plan outlines were prepared that were intended to become detailed intermodal systems plans to implement the broad guidelines of the NPN. These outlines were prepared in conjunction with the FAA and the Coast Guard and were submitted to the Secretary for approval.

These outlines were returned to RSPA with the request that they be expanded into detailed plans including budget information for presentation as a major Spring Preview Issue. Spring Preview Issues are special budget problems that are addressed in the spring of the year before the budget is prepared.

The detailed navigation plans and budgets of all DOT modes were collected and coordinated into a single Navigation Action Plan that was presented to the Deputy Secretary. A summary of this Action Plan will be included in the proceedings of this conference. During this Spring Preview, it became apparent to us that a new coordination structure was required for DOT-wide navigation planning, and the structure I just discussed was recommended to the Deputy Secretary.

These Action Plans and the creation of the Navigation Council were approved. The Secretary also assigned the Navigation Council as its first task, the review of the actual FY 80 navigation budget submission of the Coast Guard, FAA and RSPA. He also requested the council to make recommendations as to the relative priority of all requested items. We were also asked to review the budget requests against the Action Plans. This is the first intermodal exercise of this type and could set a new pattern in DOT for this type of issue.

All of the pressure points enumerated by Dr. Fearnsides raise many questions that require resolution and must be addressed by the Navigation Council. Since navigation is only a part of larger operating safety systems, changes of any magnitude involve significant impact on operating procedures. This fact, when added to the lack of definitive, current data in many of these areas, places the planning process in the position of trying to gather the necessary data and knowledge to make major decisions about the next 20 plus years of operating philosophy. These decisions now appear to be in the early 1980's time frame. Some of the more important questions under study within DOT are:

1. Will the proposed NAVSTAR GPS system furnish equal or superior service to the user community at an equivalent or lower cost to both the government and the user? A critical factor in the possible utility of GPS will be the accuracy made available to the civil sector by DOD.

2. Should the VOR/TACAN system be replaced in the post-1995 time frame? If so, with what?

NAVIGATION ISSUES FACING THE FAA

Siegbert B. Poritsky, Director
Office of Systems Engineering
Management, FAA

NAVIGATION ISSUES FACING THE FAA

Siegbert B. Poritzky
Director, Office of Systems Engineering Management
Federal Aviation Administration
Department of Transportation
Washington, D.C. 20591

I am delighted to have the opportunity to speak to this Conference on Navigation in Transportation. I am here as a substitute for Jeff Cochran, FAA's Associate Administrator for Engineering and Development, who unfortunately is unable to be with you today. Neal Blake, Deputy Director of the Office of Systems Engineering Management, will speak in some detail this afternoon on FAA's navigation activities and plans. We believe that, as an active partner in DOT Navigation Plan activities, we have a comprehensive and reasoned series of navigation efforts. I will not attempt to steal Neal's thunder, but I would like to share some thoughts with you from an overall navigation perspective.

Navigation is not a burning issue in the aviation community. As important as it is -- and it is, of course, the lifeblood of the aviation system -- most of the users with whom we deal are reasonably well satisfied. I am not suggesting that there are no problems. Many users would like better navigation and non-precision approaches to airports at significant distances from VOR/DME ground stations. Helicopter and short-haul aircraft operators need and must have precision navigation capability at very low altitudes in circumstances where VOR/DME is by no means at its best. Users interested in area navigation will insist on improvements to VOR coverage, especially where VOR's are located in difficult terrain and where there are unusable service areas. General aviation, or that element of general aviation which travels over oceans, would like a far less expensive way than OMEGA to get across the oceans. Military and large commercial aircraft operators and pilots would like improvements in altimetry to permit vertical separation of 1,000 feet above FL290. So there are indeed problems and -- as Neal will tell you -- we are attempting to attack many of those problems in our navigation program.

There are a number of people -- especially outside FAA and, in many instances, also outside the user community -- who perceive air navigation perhaps integrated with performance management computer functions, which will become the link between pilot, navigation sensors and the flight control system. There will be some sensor blending, especially at the transition points, such as between VOR/DME, RNAV and MLS, but I believe we will not see, nor do we want to see, hybridization in the classic sense. Most users are justifiably unenthusiastic about hybrid systems for strong and valid economic and technical reasons.

As my own cloudy crystal ball shows it, we will have a gradual but real evolution to wider use of VOR/DME RNAV for short distance navigation, with DME/DME RNAV coming into more use for precision high-density requirements. I believe we are likely to see implementation of some LORAN-C for special helicopter operations. For approach and landing, while ILS will be with us for a long time to come, the benefits of flexible coverage and very clean beams will have MLS replace ILS, especially for critical applications -- not only because clean beams can be provided inexpensively and with very little site sensitivity at small airports, but because noise and capacity benefits will become clear as time goes on.

Over oceans, GPS is likely to become a worthy competitor to OMEGA, but a word of caution is needed. The airlines, as the major civil users of long-haul over-water systems, were enthusiastic indeed about self-contained navigation aids, because they are virtually free from dependence on <u>any</u> ground-based or station-referenced over-water aid. Starting with Doppler updated by LORAN-A, the movement was rapid to inertial systems which provide not only high-class navigation, but offer master vertical and direction references to the aircraft as well. One of the main reasons for the airlines' current enthusiasm for OMEGA is that the cost of ownership of INS remains high and has not come down nearly as rapidly as had been expected. Yet, improvements in costs per hour of INS which have long been promised may yet materialize. When they do, it seems safe to predict that the carriers will once again find self-contained aids more attractive than either OMEGA or any other station-referenced system.

Where, then, lies the future of a unified navigation system for aviation, such as GPS? It already seems clear to us that GPS, at its best, is not likely to become the primary precision approach and landing guidance system. Perhaps I am simply showing my age, but even if the accuracy were achievable, it does not make a great deal of sense to seek information from four or five satellites thousands of miles in space to find a strip of concrete 50 feet beneath you. From the evidence we have so far, it seems unlikely that GPS will have the accuracy or the integrity to provide altitude reference better than what a good barometric altimetry system can offer. Third, it is my own belief -- perhaps prejudice -- that it is in the best interests of the aviation user to continue to segregate, wherever possible, the functions of navigation and air traffic control and surveillance.

This is important when postulating requirements for new systems because, as I said at the outset, new systems must prove to be better, not only in theoretical terms, but in practical day-to-day operations. We are attempting to grapple with this peculiar problem of rationalizing mathematical and statistical analysis with reality, and we solicit your help if we are to establish requirements for new systems which would be acceptable to the people who use the airspace, and indeed the other transportation modes as well.

Let me end where I began. Navigation in aviation does not represent a major problem to most users, although improvement in many of its services is desired. We think that major changes to the navigation systems in use today can come and perhaps should come, but they must be based on a clear understanding not only of requirements, but also of the consequences and costs of major transition.

I hope my remarks will have helped make clear that FAA's is not a Neanderthal position which advocates study of new systems to oblivion, but rather a view which calls for realistic matching of requirements and capabilities and costs, which will benefit not only the government, but the users as well.

NAVIGATION ISSUES FACING THE COAST GUARD

Rear Adm. James P. Stewart, USCG
Chief of Staff
U.S. Coast Guard Headquarters
Washington, D.C.

NAVIGATION ISSUES FACING THE COAST GUARD

Rear Adm. James P. Stewart, USCG

Chief of Staff
U.S. Coast Guard Headquarters
Washington, DC 20590

ABSTRACT. The Government has devoted considerable resources in the recent past to the development and improvement of civil maritime navigation systems. While this effort has provided a solid foundation for improved future maritime performance, formulation of long-term program direction requires resolution of certain technical, economic and operational questions. This paper presents a broad-brush view of the policy issues under study. A principal issue is the prospective future role of the NAVSTAR Global Positioning System (GPS) in civil maritime navigation, and its impact on existing radio navigation systems.

The Coast Guard has statutory authority to establish and operate aids to navigation to serve the needs of the maritime commerce of the United States. We also have the authority to provide aids to navigation to meet the military needs of the Department of Defense, when requested by an appropriate DOD official; or to serve the air commerce of the United States, when requested by the Administrator of the FAA. In the brief time allotted to me today I will concentrate on issues related to our responsibilities to the civil maritime community.

Several years ago the Coast Guard made a thorough study of the needs of all civil mariners for navigational services, and developed a plan to serve them with two primary radio navigation systems, LORAN-C and OMEGA and a short-range system consisting of visual and sound signals, radio beacons, and radar beacons. We are now several years into the implementation of that plan, and at a point where we must review it in the light of today's unresolved issues and the outlook of future navigation technology.

An issue which is of major importance to us is the future role of NAVSTAR-GPS in civil maritime navigation. Many specific questions must be answered before this issue can be decided. Nevertheless, our ability to resolve immediate questions relevant to OMEGA and LORAN-C depends to some extent upon the perspective which we and others have of NAVSTAR-GPS as a future supplement to or replacement for existing systems.

Let us look first at OMEGA where the most immediate issue seems to be system accuracy. Ongoing activities, which will be addressed later by another speaker, will provide quantitative information on the accuracy and coverage of OMEGA, as it exists, and will permit incremental improvements in accuracy over the next several years. But, it appears now that OMEGA

It provides higher efficiency and productivity in many kinds of fishing. Vessels working in the offshore industry and in scientific operations can return accurately to points where LORAN-C coordinates have been observed. A drilling ship or platform, for example, can be located accurately where a geological survey ship has found a likely place to drill. Smaller vessels - commercial fishing boats, recreational boats, and many small commercial ships - can calibrate their own home ports and inshore operating areas, and then use the high repeatable accuracy of LORAN-C to permit them to navigate accurately and safely in low visibility.

There are many applications for the use of this feature of accurate repeatability on land. Extensive overland use not only would provide greater benefits from the Government investment in LORAN-C than would maritime use alone, but also would provide a much larger potential market for LORAN-C receivers. A larger market would further reduce receiver costs and make LORAN-C service a practical reality for many more small vessel operators, many of whom sail in exposed coastal and offshore waters with less than adequate navigational capability.

The points I have made apply to the coastal LORAN-C system now being implemented. There are, however, various techniques that can be used to improve both the repeatable and geodetic accuracy of LORAN-C selectively, in a small area such as a seaport. With proper design the geodetic accuracy of LORAN-C in a given area can approach the maximum achievable repeatable accuracy which we believe to be less than 50 feet. Through R&D we are attempting to develop this characteristic of LORAN-C for use in improving the safety of navigation in restricted harbor channels and inland waters, on a selective basis, depending on the relative cost and benefit in each instance.

Let us look now at NAVSTAR-GPS.

Though the maximum inherent accuracy of NAVSTAR is expected to be very high, there are some legitimate technical questions concerning its ability to deliver that accuracy in all applications where LORAN-C is or might be used. There is a critically important policy question also. Will the United States give the entire world, and thus a potential enemy, unrestricted access to the same navigational service which is being developed to improve the military capability of our armed forces? Even if the maximum expected accuracy of NAVSTAR were achievable in all civil applications, and if it were made available for unrestricted worldwide use, the cost of a receiver capable of achieving that accuracy certainly would be beyond the means of most of the smaller operators who constitute the vast majority of civil maritime users of Coast Guard-operated radio navigation systems. Regardless, therefore, of the relative influences of technical performance and government policies, a basic question about NAVSTAR which we must consider is "What range of performance will be available to the civil community, and at what cost?"

To formulate objective decisions concerning the navigation service, or mix of services, which the Government will provide to the civil community, we need to examine all potential safety, economic, and other societal benefits of each alternative, in the light of corresponding costs to navigation information which is provided to a large ship, and the effectiveness with which that ship can be navigated through a channel of given shape and dimensions under various environmental conditions. We also need to develop more detailed measures of the performance obtainable through each of several alternative methods which might be used to improve LORAN-C service in any given local area.

I have been discussing OMEGA, LORAN-C, and NAVSTAR primarily from the viewpoint of general maritime navigation. The management of maritime traffic, however, is a subject of increasing interest and activity, and one which raises issues related directly or indirectly to navigation systems planning. The first and primary criterion for effective management of traffic, wherever it flows in structured patterns is in restricted harbor channels, or in traffic lanes and fairways in open coastal waters, is the provision of aids to navigation service adequate to enable ships to navigate within the limits of paths intended for their use. In some critical congested areas, additional measures are taken to exercise surveillance over the flow of traffic, and to issue advisory information or instructions to shipping when appropriate or necessary. Wherever surveillance is exercised, we must choose between dependent surveillance, in which we rely upon ships themselves to report their positions intermittently, or independent surveillance in which the locations and movements of ships are observed from shore without any dependence upon any navigational equipment aboard ship. The quality of dependent surveillance, when used, relies upon the accuracy and frequency with which ships can report their positions. While in the management of maritime traffic, there are a number of factors that enter into any choice between independent and dependent surveillance, the quality of aids to navigation services is obviously one important consideration.

Finally, I should point out that, in our planning of maritime aids to navigation systems, we must remember that the majority of larger commercial ships which use our coastal waters and ports are foreign vessels. To optimize the services which we provide we must be in a position to persuade or require foreign ships to use them.

While it is true that we have the authority, as a nation, to issue requirements applicable to any ship which enters our ports, it is equally true that there are limits as to the extent to which we can exercise this right without generating adverse effects on our foreign commerce or on U. S. ships engaged in foreign trade. Acceptance by the international community of the system or systems which we operate is a very important consideration.

NAVIGATION ISSUES FACING THE SAINT LAWRENCE SEAWAY DEVELOPMENT CORPORATION

William H. Kennedy
Associate Administrator, SLSDC

NAVIGATION ISSUES FACING THE SAINT LAWRENCE SEAWAY DEVELOPMENT CORPORATION

William H. Kennedy

Associate Administrator SLSDC
and Resident Manager SLSDC
P.O. Box 520
Messena, NY 13662

It is a pleasure to be a part of this program with the distinguished members of the U.S. Department of Transportation. It's also nice to visit the Transportation Systems Center with whom we have been working to develop electronic navigation aids for use on the Seaway.

The Saint Lawrence Seaway Development Corporation is a wholly owned United States Government Corporation, an operating Administration within the U.S. Department of Transportation. It is a business organization operating under The Corporation's Act. We operate on user charges, with all of our income being derived from tolls that ships pay to use our facilities. In addition to covering the costs of operations, administration, maintenance and capital expenditures, we also return monies to the U.S. Treasury each year to redeem U.S. Treasury bonds issued to provide the funds which were required when the Seaway Development Corporation facilities were built. Our enabling legislation charged us with the responsibility to design, build and develop the navigation facilities in U.S. waters, to promote deep-draft navigation in the St. Lawrence-Great Lakes Seaway System. The charge was to accomplish this in conjunction with our Canadian counterpart, the St. Lawrence Seaway Authority of Canada. In addition to building and operating the facilities themselves, it became necessary for the two seaway entities to establish joint international rules and regulations for the operation of the seaway system from Montreal to Lake Erie, and it also became necessary for them to jointly establish adequate tolls to provide funds to cover the cost of our operations, administration, maintenance and capital expenditures. That is why one of the most challenging issues we have is the development of a navigation aid system which we can afford, because it must be paid out of revenues we receive from the shipping community.

Another important cooperative venture we have with the Canadians is our vessel control system. This is a sector system established jointly with our Canadian counterpart and based on international operating procedures. Under these procedures, the Canadians may control traffic in U.S. waters and we, in turn, may control traffic in Canadian waters.

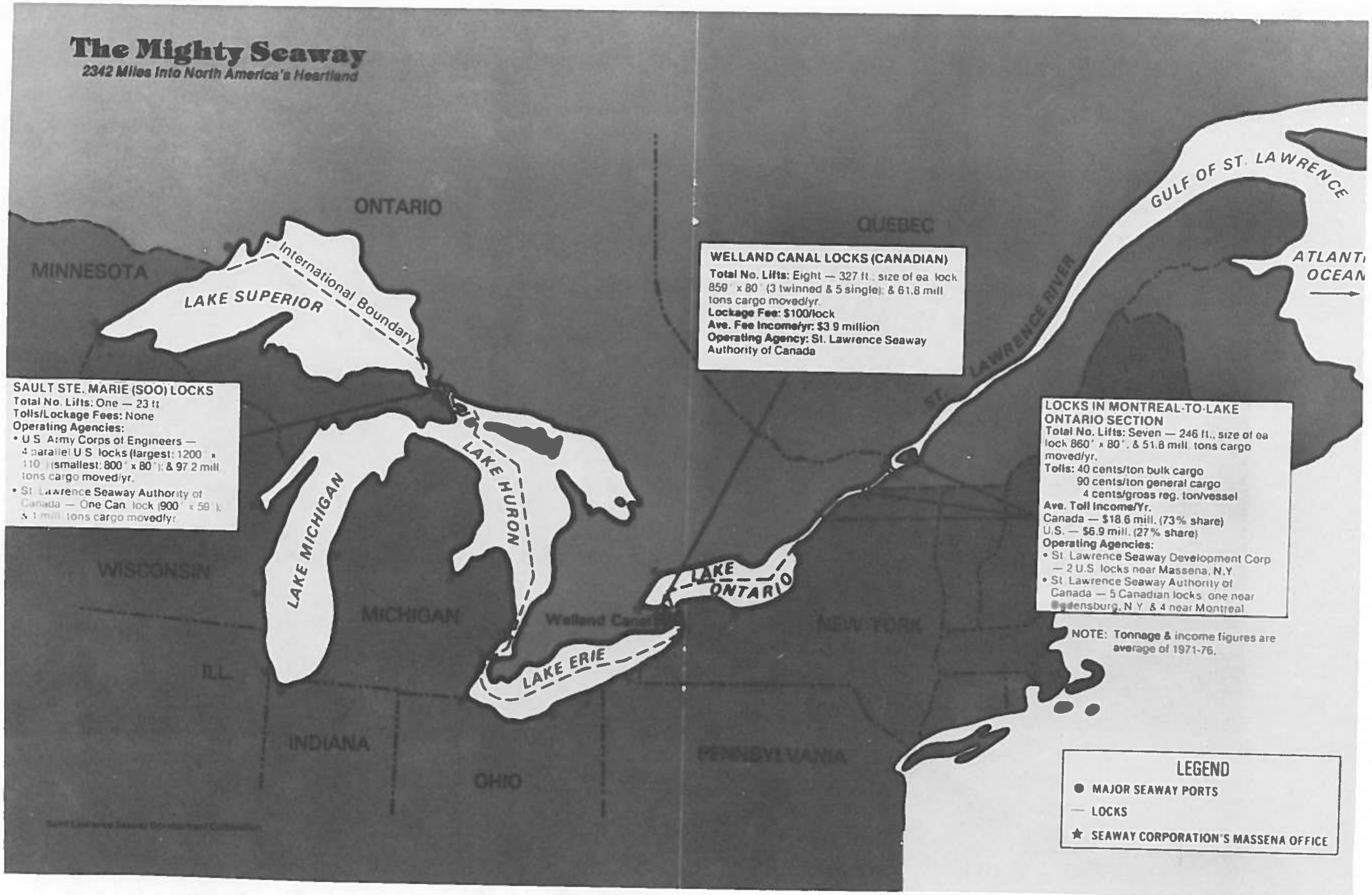

FIGURE 1 THE MIGHTY SEAWAY

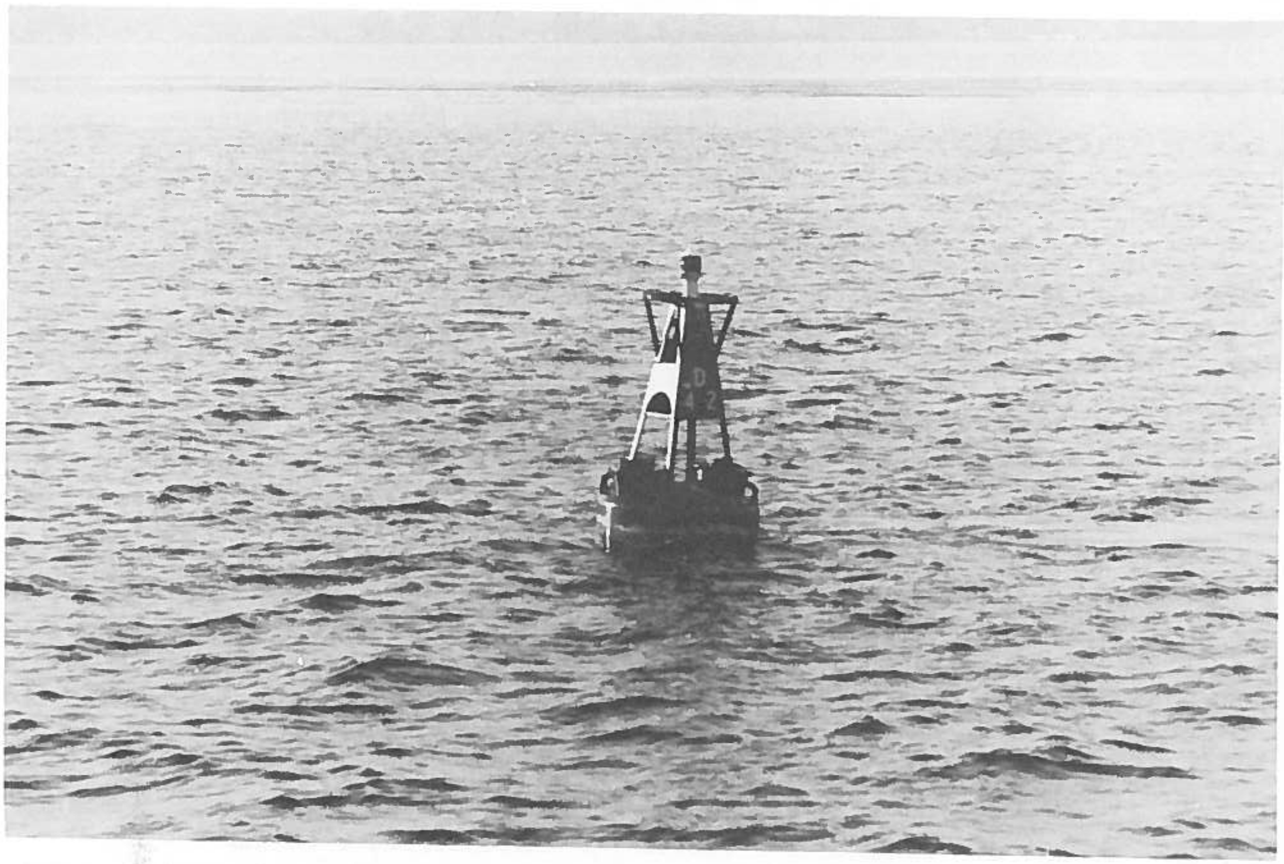

FIGURE 3 TYPICAL LIGHTED BUOY

decided that we should maintain our own navaid system. We now maintain all of the aids, both fixed and floating in that part of the Seaway from St. Regis, Quebec to Lake Ontario which lies in U.S. waters. As you can well imagine, in order to prevent their loss, or damage to them, all of the floating aids must be removed from the river when the ice begins to form.

In recent years, The Congress of The United States established a winter navigation program to investigate the feasibility of extending the navigation season in The Great Lakes - Saint Lawrence Seaway System, as well as demonstrating season extension feasibility with specific demonstration programs.

A winter navigation board, outlined in Figure 4, made up of representatives from these government agencies was established to carry out the season extension program investigation.

recently concluded evaluation tests. Later on, in this conference, Lt. Dave Olsen will be discussing the results of these tests.

In the meantime, MARAD was phased out of this responsibility on the winter navigation board and was replaced by the Saint Lawrence Seaway Development Corporation. We enlisted the aid of TSC as we proceeded to formulate thoughts relative to an improved navigation system. One of the first things we did with TSC was to initiate a study to define requirements and potential benefits before any particular system or systems could be adopted.

The Arctec Corporation, under contract to TSC has just completed a study of navigational system requirements which will effect improvements in the capacity of the Seaway.

The results of the study will be presented in a final report that is now in publication, a few highlights of the report, however, are very appropriate for consideration now.

You will recall that the normal shipping season starts about April 1st and ends about December 15th each year.

The extended season here is the period between December 15 and April 1st.

Note in Figure 5 that with the implementation of an electronic navigation system with an accuracy of at least 30 feet, an all year increase of about 30% in capacity could be expected.

CAPACITY

Salty Class Ship $T_{ice\ lock}=0$ $V_{ship} = V_{speed\ limit}$		NORMAL			EXTENDED			ALL YEAR		
Year	Condition	Yearly	4 yr avg	% Increase Over 4 yr avg	Yearly	4 yr avg	% Increase Over 4 yr avg	Yearly	4 yr avg	% Increase Over 4 yr avg
1 2 3 4	No electronic navigation aids	8131 8163 8227 7715	8059	NA	1762 1723 1631 1428	1636	NA	9893 9886 9858 9143	9695	NA
1 2 3 4	0'	9555 9586 9557 9558	9564	18.7	3134 3019 3035 2881	3017	84.4	12689 12605 12592 12439	12681	29.8
1 2 3 4	30'	9541 9581 9550 9555	9567	18.6	3129 3020 3035 2881	3016	84.4	12670 12601 12585 12435	12673	29.7
1 2 3 4	60'	9257 9286 9188 9078	9202	14.2	2934 2895 2938 2880	2912	78.0	12191 12181 12126 11958	12114	25.0
1 2 3 4	100'	9066 9133 9072 8829	9025	12.0	2748 2767 2768 2724	2752	68.2	11814 11900 11840 11553	11777	21.5
1 2 3 4	160'	8918 8887 8875 8572	8813	9.4	2709 2642 2667 2670	2672	63.3	11627 11529 11542 11242	11486	18.6

FIGURE 5 SALTY SEAWAY CAPACITY AS A FUNCTION OF NAVIGATIONAL SYSTEM POSITIONING ACCURACY

Figure 7 demonstrates near term potential benefits because, unlike winter navigation, it does not depend on extensive dredging operations and the use of new ice booms. Here you can see that a electronics navigation system, with an accuracy of zero to 30 feet would bring about a susbtantial increase in Seaway capacity in the normal season alone. Based on the overall cargo tonnage handled by the Seaway in 1977, this could mean an increase to the shipping community of 10 million tons annually.

Salty Class Ship $T_{ice\ lock}=0$ $V_{ship}=V_{speed\ limit}$		NORMAL SEASON CAPACITY		
Year	Condition	Yearly	4 yr avg	% Increase Over 4 yr avg
1 2 3 4	No electronic navigation aids	8131 8163 8227 7715	8059	NA
1 2 3 4	0'	9555 9586 9557 9558	9564	18.7
1 2 3 4	30'	9541 9581 9550 9555	9557	18.6'
1 2 3 4	60'	9257 9286 9188 9078	9202	14.2
1 2 3 4	100'	9066 9133 9072 8829	9025	12.0
1 2 3 4	150'	8918 8887 8875 8572	8813	9.4
1 2 3 4	200'	8711 8605 8586 8194	8524	5.8
1 2 3 4	250'	8554 8537 8573 8072	8434	4.7
1 2 3 4	300'	8462 8409 8499 7930	8325	3.3

FIGURE 7 SALTY SEAWAY CAPACITY AS A FUNCTION OF NAVIGATIONAL SYSTEM POSITIONING ACCURACY

The demonstration of new ice booms is scheduled to take place in a small section of the Seaway this winter. The second part of the season extension demonstration program will take place next summer. The purpose of the summer program is to demonstrate the feasiblity of electronic navigation aids for the Seaway.

In Figure 8, a test vessel with a CRT display will receive signals from conventional LORAN C; a RAYDIST "T", phase measurement system and a precision reference system which we have not yet acquired.

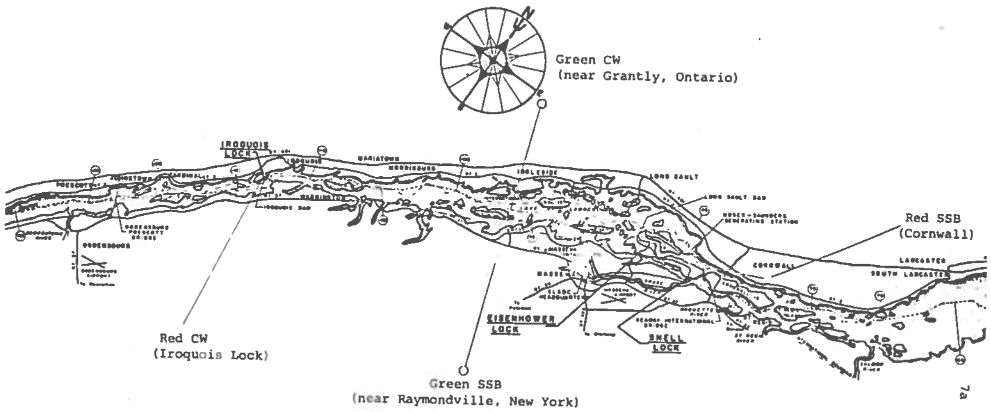

FIGURE 9 RAYDIST "T" GEOMETRY

As a result of our navaids program we can see considerable economic benefits to The Corporation, as well as to shipping and consumer interests. We expect substantial gains in our continuing efforts to achieve safe and efficient operations. We will have taken a giant step toward our goal of making the Seaway a leader in the development and use of contemporary technology.

SESSION II
NAVIGATION PLANS

The Center for Navigation at TSC
Chairman
Dr. Paul Abramson, Chief
Systems Technology Division, TSC

THE CENTER FOR NAVIGATION AT TSC

Dr. Paul Abramson

Chief, Systems Technology Division
Transportation Systems Center
Kendall Square
Cambridge, Mass 02142

Good Afternoon:

This morning you heard Dr. Palmer describe a newly formed DOT Administration, the Research and Special Programs Administration. In his remarks, he made reference to a Navigation Center at the Transportation Systems Center. I would like to spend a few minutes talking about this newly formed Navigation Center, outlining its current activities, and plans we have for supporting the Department, the modal administration and the users of civil navigation systems.

Perhaps it would be appropriate to first say a few words about the Transportation Systems Center so you can get a better idea about how our work fits in with respect to the Department and the operating administrations of DOT.

TSC is the Department's multimodal systems research, analysis, and development organization performing high priority technological and socio-economic research for the Secretary of Transportation and all of The Modal Administrations. We perform this work directly for the Department as well as in support of the various modes such as FAA or Coast Guard. TSC's work in navigation is structured in a similar manner. We support the Department through RSPA in what we call a Core Navigation Program. The focus of this Core Program is multimodal applications of navigation systems and support to the Department in making decisions that potentially affect more than one mode. However, an equally important part of TSC's activity is our work for the various elements of DOT.

You will be hearing more about these projects in the next two days. We feel it is important to have a proper mix of departmental and modal programs. Through the modal programs, we can gain experience and insights into specific navigation system problems and users. Through departmental programs, we can get an overview of the similarities <u>and</u> differences between the modal and user requirements, and systems to meet those requirements. At the risk of oversimplifying, let me outline three problems facing the Department which lead directly to three objectives that we hope the Navigation Center at TSC can assist in accomplishing.

formation that is gathered by TSC, various other elements of DOT, and other governmental organizations.

TECHNOLOGY ASSESSMENT

The first area, Technology Assessment, deals with the first problem I previously mentioned, assessing a rapidly emerging technology base. Included in this area are such diverse fields as:

- SATELLITE TECHNOLOGY
- RADIO FREQUENCY PROPAGATION
- DISPLAY AND PROCESSING TECHNOLOGY
- HUMAN FACTORS
- ANTENNA DESIGN
- INTEGRATED AND LOW COST USER EQUIPMENT

NAVIGATION SYSTEM ANALYSIS AND PLANNING

The second area, Navigation System Analysis and Planning support also encompasses a multitude of activities, such as:

- EXAMINATION OF SYSTEM AND USER PERFORMANCE REQUIREMENTS
- BENEFITS ANALYSES
- NAVIGATION SYSTEM MODELLING
- SYSTEM COST ANALYSES
- EVALUATION OF ALTERNATIVE SYSTEM MIXES

Included in this second area is acquiring the necessary data that I mentioned earlier to support navigation system decisions in the future.

TECHNOLOGY INFORMATION AND SHARING

The last area of focus is technology and information sharing, as outlined below:

- INTERFACE TO STATE AND LOCAL GOVERNMENTS AND AGENCIES
- STRONG INFORMATION DISSEMINATION EFFORTS
- NAVIGATION CONFERENCES
- PERIODIC STATUS REPORTS ON SYSTEM/TECHNOLOGY DEVELOPMENTS

RSPA AND LAND NAVIGATION ACTION PLAN

William B. Mohin
Research and Special Programs Administration

RSPA AND LAND NAVIGATION ACTION PLAN

William B. Mohin

Department of Transportation
Research and Special Programs Administration
Washington, DC 20590

ABSTRACT This paper outlines two of the Navigation Action Plans that have been prepared to implement the National Plan for Navigation.

The Research and Special Programs Administration Plan and the Land Action Plan are described.

Dr. Fearnsides mentioned this morning that navigation action plans have been prepared for all modes in DOT. Specifically there has been Air, Marine, Land and RSPA action plans prepared that cover the next five years of radio navigation planning and funding. These action plans are intended to implement the DOT National Plan for Navigation which provides general guidance and identifies major decision points. RSPA presently prepares two of these action plans. One for our role in departmental navigation coordination discussed this morning by Dr. Palmer and the other is the Land Action Plan.

In the RSPA Action Plan we will continue, at the Transportation Systems Center, a DOT program to build a more comprehensive intermodal technical capability and data base in the area of radionavigation. New efforts to be initiated in FY 78 include:

1. Acquiring a strong NAVSTAR GPS technical base in order to assess its potential for civil use based on present DOT plans. A determination will be made as to what technical changes, if any, are possible and feasible to make this system more responsible to civil needs. The costs and benefits of civil use of the proposed system and any proposed changes will be analyzed.

2. Analysis of DOT plans and navigation experiments to aid in preparation of follow-on editions of the DOT National Plan for Navigation.

fall. If an affirmative decision is made on providing this Loran C service, the following actions will be implemented:

- Designate the U.S. Coast Guard as the operating DOT Administration for this service. The Coast Guard will construct and operate the stations and establish specifications and standards to guarantee full utility of this service;

- Designate the Transportation Systems Center as the DOT element responsible for applications, technical information and technology transfer to Federal/state/local entities and to the general public.

  <u>AND</u>

- Conduct Loran C use experiments by the Urban Mass Transportation Administration, National Highway Traffic Safety Administration, Federal Highway Administration and the Federal Railroad Administration. Most of the current experiments in this area will be the subject of individual papers during the next two days.

These plans establish RSPA's actions to coordinate DOT's navigation planning and to thoroughly investigate the potential for land use of Loran C signals. They represent our best estimate at this time of the work required to support future policy decisions by the Secretary.

FAA NAVIGATION PROGRAM

Neal A. Blake, Deputy Director
Office of Systems Engineering Management
FAA

FAA NAVIGATION PROGRAM

Neal A. Blake

Deputy Director, Office of Systems Engineering Management
Federal Aviation Administration
Washington, D. C. 20591

The FAA navigation program includes two major activity areas: those associated with certification of navigation systems to meet current requirements and those associated with building the data base needed to define future system improvements.

The near-term activities include the VORTAC upgrading program, the development of the technical data base needed for certification of LORAN-C and OMEGA as a part of the current air navigation system, and the completion of development of area navigation standards. It also includes a realistic assessment of the operational suitability of Differential OMEGA to provide supplementary coverage to the VORTAC system in meeting special user requirements in Alaska. A new initiave in the near-term program this year is the Helicopter IFR Program, which includes, as a part of the overall program activity, an assessment of the operational suitability of the several navigation system alternatives for meeting helicopter navigation requirements for CONUS and offshore operations.

Our future system activities include analysis of alternative system configurations made up of system elements including VORTAC, VOR-DME, OMEGA and Differential OMEGA, LORAN-C, and GPS. This analysis includes cost-benefit tradeoff studies, as well as technical evaluations. In conducting this activity, we are placing emphasis on examining the potential future role of the Global Positioning System (GPS) for air navigation.

Figure 1 shows the interrelationships between the near and far term programs. The second generation VORTAC upgrading program will result in a replacement of the current obsolete equipment during the 1980-1984 time period. We fully expect that the ICAO nations will request extension of the VOR-DME protection date from 1985 to 1995, as many of the third world nations have only recently made, and many are now making, substantial investments in both the ground and airborne portions of the system. We believe that the United States is likely to support this position.

The offshore and remote area activities include the programs needed to certify LORAN and OMEGA for special user needs and oceanic area navigation in the near term and to provide the data base needed for determination of the potential role of these systems as a part of the future navigation system. In oceanic areas, OMEGA has already been certified as an updating aid to systems like Inertial and Doppler. Our current program encompasses the activities needed to establish the data base for certifying OMEGA as a primary aid for air carriers operating in oceanic areas. We plan to have this latter work completed in time for a decision during FY-80.

The future systems work is keyed to completing the studies, analysis and feasibility tests needed to make the decision on the future roles of each of the system elements by the 1983-85 time period. After the decision is made we expect that the transition will take some 10 to 15 years. Our cost studies have indicated that this time period results in the lowest overall costs to both the government and users. In realistic appraisal of the aviation system, this order of transition period is probably conservative in practical terms.

VORTAC UPGRADING PROGRAM

The goal of the solid-state VORTAC VOR-DME replacement program is to replace obsolete VOR-DME and TACAN electronic equipment, which are up to 34 years old, with new equipment. We expect the mordernization program will reduce the current operations and maintenance costs for the VORTAC system from $37 million to about $16.4 million, - for an expected annual savings of $20.6 million. Of this, approximately 60 percent of the savings will result from use of solid-state technology. The remaining 40 percent will be derived from reduction of operation and maintenance costs through use of a remote maintenance monitoring capability. The program will provide full recovery of investment costs by the late 1980's, and seems to be a very sound investment.

LORAN-C

The objective of the LORAN-C program is to determine the suitability of this system as a supplement to and possible replacement for the VOR-DME system. This program addresses the issues of LORAN-C signal availability and reliability; the performance of the LORAN-C system for en route, terminal, and non-precision approach operations; and the feasibility of developing low-cost avionics, particularily for general aviation.

The activities being carried on under the LORAN-C program are part of a joint program between the FAA and United States Coast Guard. This joint effort includes establishing a LORAN-C data base, developing a LORAN-C monitoring system, evaluating various avionics equipments, developing low-cost avionics equipment, developing geographical grid corrections, and determining the impact of using LORAN-C navigation on air traffic control (ATC) and flight inspection procedures.

There are several cooperative interagency activities in the program to establish a data bank on LORAN-C performance. FAA is providing a portable ground test facility to determine short-term variations in LORAN-C signal stability. This facility will be used in support of flight tests at airports where the FAA will be evaluating use of the LORAN-C signals for non-precision approaches. FAA aircraft will be used to gather data at airports located in the Northeast Corridor, offshore along the East Coast, in Alaska and along the West Coast. During the same time period, NASA will be examining the long-term variations in the LORAN-C signal to determine seasonal variations.

nals and identifies the stations of choice for use in each geographical area. This information is provided to FSS's and Centers, and will be passed on to the pilots through NOTAMS. We are planning to extend the monitor system to include VLF monitoring capability and later to add use of information from SOLARD system - a satellite system which detects and reports information on solar flares.

Since the OMEGA system operates at very low signal-to-noise ratios, one program activity has been to develop a low noise antenna. This antenna has received some testing on a National Oceanic and Atmospheric Administration (NOAA) aircraft; however, the time available for such testing has been quite limited and the antenna is being transferred to the FAA Alaska Region for flight inspection aircraft for further testing and evaluation. Future activities under the noise reduction program include studies of alternative methods of noise reduction, further antenna research and determination of improved methods of discharging and bonding aircraft.

An OMEGA simulator is being developed to permit rapid evaluation and certification of new OMEGA receiver designs. It will simulate a variety of signal-to-noise conditions of the OMEGA signal as well as station failure conditions.

This fall, we hope to start an evaluation program with Canada on a Differential OMEGA system. Three non-directional beacons will be equipped to transmit the Differential OMEGA corrections to the aircraft. The evaluation will be conducted over the next year in the Alaska Region, and will involve the FAA flight inspection Convair, a Twin Otter owned by the Canadian Government, and some cooperating commercial aircraft operators. It is anticipated that six sets of avionics will be available for the program.

The future program activity will include development and evaluation of low-cost OMEGA avionics. At the current time, low-cost equipment is available in the $6,000 to $8,000 price range. It is hoped that this amount can be reduced to the $3,000 to $4,000 range.

HELICOPTER IFR PROGRAM

A new start for FAA this year is a program to examine the special requirements of helicopters for operation within the air traffic control system, both within the CONUS and in offshore areas. The portion of this program, relating to navigational requirements covers the operational evaluation of LORAN-C and OMEGA, as well as VOR-DME and DME-DME, for operations on area navigation routes within the CONUS, and on specially defined routes suitable for supporting offshore oil exploration. The program will also examine the use of airborne weather radar in conjunction with supplementary equipment to assist in locating and making approaches to offshore oil rig locations. This latter activity will examine the effectiveness of several techniques including active beacon systems, passive reflectors, corner reflectors, and a variety of RF lenses for this purpose. Data collection will be conducted using a NASA CH-53H helicopter operating along the area navigation routes between Boston and Washington National Airport. Initially, the TDL-424 LORAN-C receiver will be used to take the data. Later tests will take comparative data on both the TDL-424 and the lower cost TDL-711 systems. Another FAA effort will be data collection taken by the FAA/NASA helicopter operating in the offshore area in the vicinity of Atlantic City. The data collection system will simultaneously be taking

The availability of signals of adequate accuracy at all times, including times of stress, is perhaps the most important institutional factor. A preliminary evaluation of the GPS signals as they are currently proposed indicates that many of the civil requirements could probably be met with the clear acquisition (C/A) channel signal. Currently the Department of Defense is studying the questions of signal accuracy and availability which might be offered for civil navigation and expects to release the results of the first portion of this study later this month. If the currently hoped-for accuracy of the clear/acquisition signal were available at all times, except for conflicts involving the immediate safety of the United States, then GPS becomes an attractive alternative for the future civil navigation system. We believe the civil user community will be very much interested in GPS if it can offer a better service than current systems at a lower user cost.

A closely related issue is the suitability and international acceptability of a U. S. military system for international civil aviation use.

TECHNICAL FACTORS IN GPS

While it is believed that avionics can be built for large air carrier aircraft that will perform satisfactorily, there is still a question on the feasibility of developing low cost user equipment that will operate satisfactorily with the GPS signal. Of particular concern is the ability to achieve the necessary accuracy for non-precision approaches using low-cost equipment, when the aircraft is in a maneuvering configuration at low altitudes in the terminal area. In this configuration, the aircraft is subject to the greatest amount of ground-generated radio frequency interference which is added to that environment that the aircraft is most subject to multipath problems.

Aircraft antennas become a consideration as it is necessary to obtain suitable signal-to-noise ratios even at very low satellite elevation angles, such as 5° above the horizon. This is necessary in order to track at least four satellites in good geometry throughout non-precision approaches.

Acquisition time becomes a consideration both on initial code acquisition and on airborne reacquisition after signal loss. It also is a consideration when it is necessary to receive ephemeris data when picking up a new satellite. This condition will occur whenever one of the satellites required to achieve a good position fix is just coming into view over the horizon. A related issue currently under study is the effect of satellite failures on system accuracy, particularly as it might affect aircraft involved in non-precision approach operations.

Alternative signal formats are being examined to determine the potential for reducing avionics cost. Although some cost reduction appears achievable with a different signal format, the change offering the greatest gain seems to be the provision of additional power in the satellite utilizing the current signal format.

The human factors area must also be considered as the GPS system, by definition, is an area navigation system. Such a system represents an increase in pilot workload over the VOR system, particularly for single pilot IFR operations. It also increases the possibility for blunders in entering way-point information.

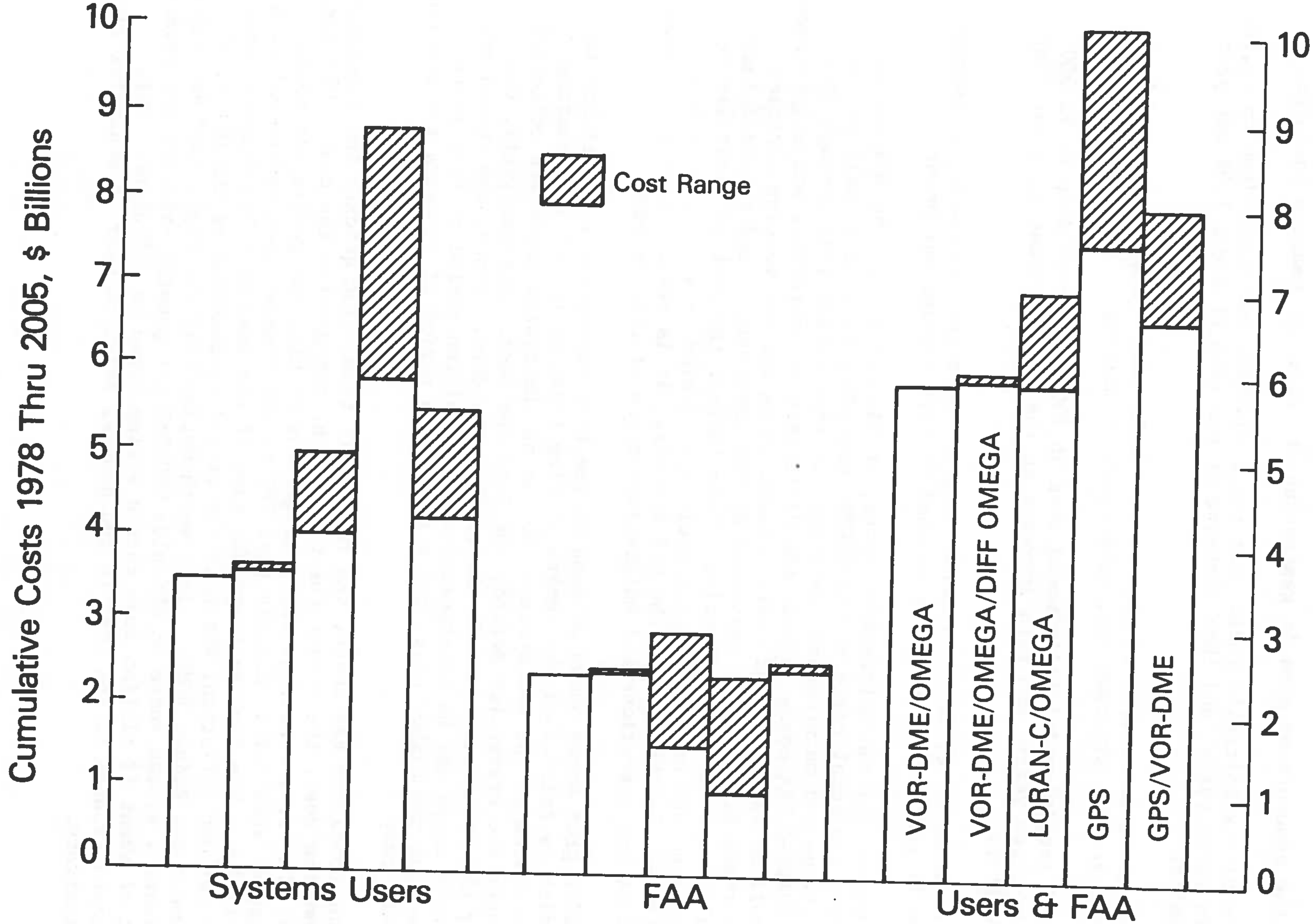

FIGURE 2. COST ALTERNATIVES FOR FUTURE CIVIL NAVIGATION SYSTEM (ASSUMING 7% INFLATION)

GPS PROGRAM

The program includes activities to define future civil navigation requirements and to evaluate the performance of the GPS system in meeting these requirements. It includes use of GPS simulators to rapidly test receiver equipment, and flight tests to evaluate the performance of existing equipment and to determine the noise and radio frequency interference environment as it exists at a number of airports where non-precision approaches are currently being conducted.

A continuing cost analysis is being conducted on the various aviation navigation system alternatives. The FAA has already completed a preliminary evaluation of alternative navigation systems for civil air navigation. This effort will be expanded in FY-1979 to examine additional alternatives particularly with respect to distribution of operating and maintenance costs among the civil users. FAA is supporting the Office of the Secretary and the Transportation Systems Center in cost analysis studies of various navigation system mixes applied not only to aviation, but also to maritime and land users.

A third major effort relates to design studies for a low-cost GPS receiver. This includes alternative design studies and evaluation, alternative signal structure studies, technology forecasts, antenna studies, radio frequency interference studies and measurements, and avionics receiver costing activities.

While much of the preceding material on institutional, technical, and cost factors raises questions; we believe that GPS may well play a significant role in future civil air navigation. In oceanic and low density traffic areas worldwide, we believe that there may indeed be an incentive for air carriers and commercial operators to carry such a system, since it offers a potential for the elimination of the need to carry systems such as INS, which currently have high maintenance costs. Hence, GPS may offer a cost effective system for operations over as much as 90% of the earth's surface. Aircraft equipped with GPS will be able to utilize the system within the CONUS airspace. Initially such use might be possible in the high altitude route structure providing a direct routing capability much like that available from the INS system today. This would require no changes to current ATC procedures. In the future, it might also provide the possibility of non-precision approaches; however, new charting and new waypoint systems will be needed which match the capabilities of the GPS system. GPS may also meet some special user requirements, such as in offshore oil exploration. Initially, the cost of receiver equipment appears to be comparable to that of existing OMEGA receivers. For the longer term, particularly if the low-cost user GPS avionics cost goals can be met, it may also become competitive to the cost of LORAN-C receiver equipment.

While we can foresee GPS in meeting these requirements, it is not yet clear whether GPS can meet the requirements for low cost user avionics, which represent the majority of the civil users within the continental United States. GPS should not be considered as a replacement for VORTAC until avionics are available in the $2,500 or lower price range, and until we are sure that such avionics can provide an adequately high level of failure detection and safety.

COAST GUARD NAVIGATION PLANS

Cdr. Robert Fenton
Office of Marine Environment

COAST GUARD NAVIGATION PLANS

Cdr. Robert E. Fenton, USCG

Aids to Navigation Division
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ABSTRACT: Under its statutory authority, the Coast Guard provides aids to navigation to maritime civil and military users on the high seas, in the U. S. Coastal and Confluence Zone (CCZ) and in Harbor and Harbor Entrance (HHE) areas, and to aviation users as requested by the Federal Aviation Administration. Each of these services is geared to satisfaction of the functional requirements of particular segments of one or more of these user groups. Thus, the systems collectively facilitate movement of the commerce of the United States, provide safety of navigation for protection of life and property at sea, protect the environment and contribute to the national defense. While considerable expansion has already been completed in the Loran-C and OMEGA radio navigation systems, improvements and selected expansion/consolidation are contemplated in the total navigation mix to develop fully their potential in a multi-user environment. This paper describes Coast Guard plans over the near-term (1980s) to effect that improvement in civil navigation.

INTRODUCTION: There are four Coast Guard-operated radionavigation systems presently providing services to marine users: Loran-A, Loran-C, OMEGA and radiobeacons. The Short Range Aids to Navigation System forms a complementary set of audio-visual signals to enhance vessel navigation. In view of the DOT decision in 1974 to designate Loran-C as the Government-provided radionavigation system for civil marine use in the U. S. CCZ, as well as the concurrent development of the OMEGA system for world-wide navigation, Loran-A is being phased out with all U.S. operations scheduled to end in December 1980. At that time, Loran-C and OMEGA will have superseded the existing Loran-A coverage, albeit with some deficiencies that will be highlighted subsequently. These systems will remain in operation at least until 1995, evolving over time to serve a broad range of distinctly different user requirements in all transportation modes. The ultimate mix of marine navigation systems in the post-1995 time frame is a matter of considerable conjecture at this time, the resolution of which is dependent upon further developments and study.

While recognizing the long-term uncertainty implicit in these issues, the Coast Guard has developed an action plan that seeks to remedy existing deficiencies in a cost-effective way while undertaking the research and analysis needed to sustain informed policy judgements for the future.

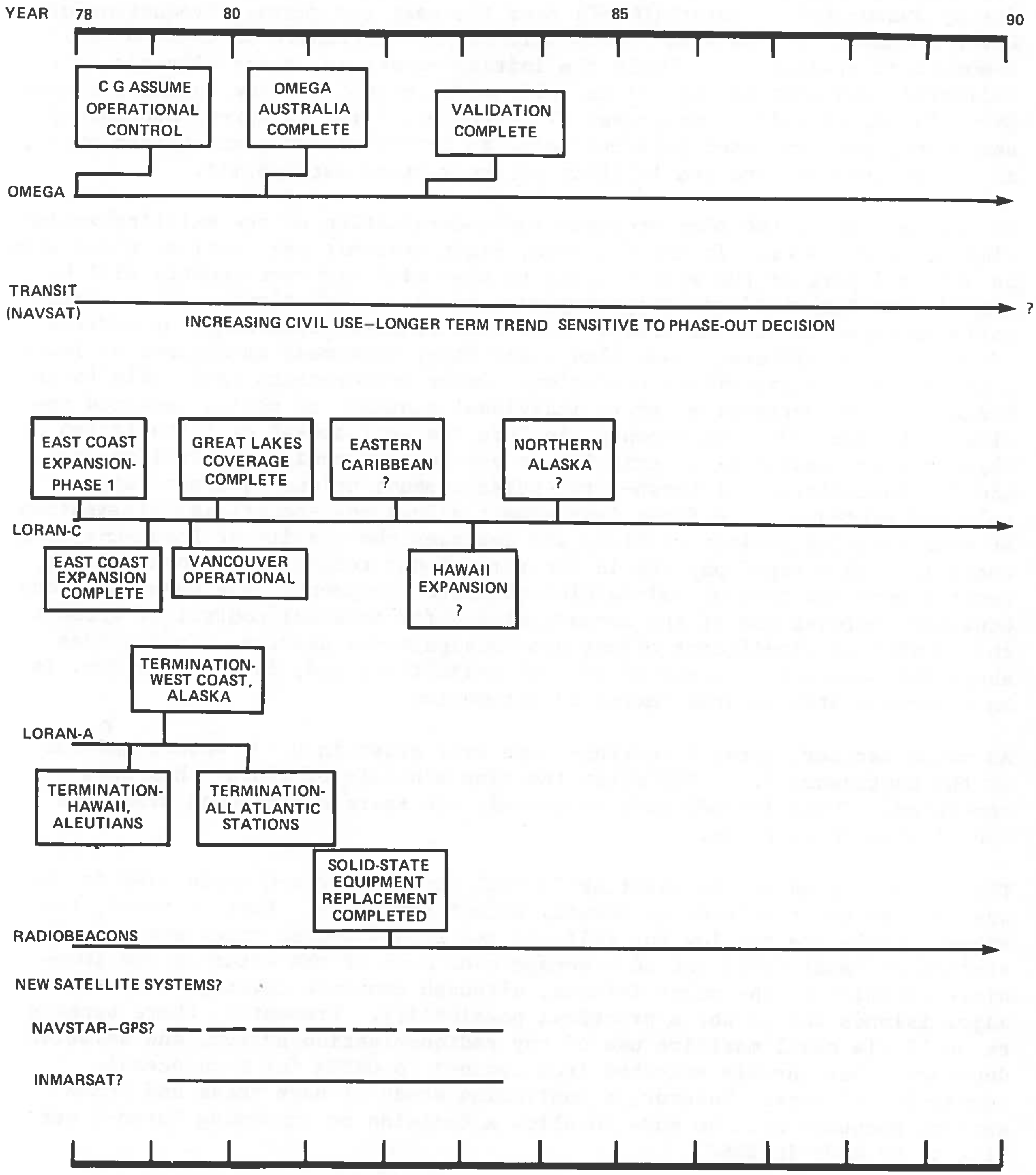

FIGURE 1: MAJOR MARINE RADIONAVIGATION SYSTEMS TIMETABLE

incremental but unquantifiable insurance against accident risk.

Two basic alternatives are under study to provide additional coverage. The first is a midi-chain of 3 medium-power stations, all of which would be located on U. S. territory. It would provide useful local service over the U. S. CCZ waters, but with a marginal accuracy (probably poorer than 1/4 NM with typical low-cost receiver) in much of the service area. Station location has not been determined, and is likely to be a problem in terms of finding suitable sites. The second alternative is a wide-area chain of high-power Loran-C stations with most or all on foreign soil. As compared to the first approach, it offers a lower annual cost per square mile of coverage with a higher initial capital investment, and the relative quality of service in the Puerto Rico/Virgin Islands CCZ would be dependent on the location of the baseline extension beyond any station built on U. S. territory. A recommendation on expansion will be made after further assessment of the alternatives and review of OMEGA coverage in the area.

There is no Loran-C service in Northern Alaska, either offshore north of the Bering Strait or over the continental land mass. OMEGA coverage is fairly good in the area but not accurate enough for maritime navigation nearshore. However, it appears that the current low volume of marine traffic can be served by OMEGA, with visual and radar piloting satisfying inshore navigation requirements. The FAA will evaluate both Loran-C and OMEGA for air navigation in remote-area air-space, including Northern Alaska. Pending their evaluation and an initial review of prospective maritime requirements in 1980, no action is planned before at least 1982.

The Coast Guard is developing Loran-C for use as a precision navigation system in Harbor and Harbor Entrance (HHE) areas. A mini Loran-C chain installed in the St. Marys River is being evaluated to establish the capabilities of a short chart baseline Loran-C chain, configured specifically for precision navigation in a localized area. This subject is treated much more extensively in other papers, and so will not be repeated here.

Two other items are worthy of note. Work is underway to develop a specification for the Loran-C signal. A preliminary specification was used in the development of a Minimum Performance Standard (MPS) for Loran-C receivers by the Radio Technical Commission for Marine Services (RTCM). This latter effort may be especially significant, since its product will furnish the technical regulatory basis for navigation receivers if they should become required aboard merchant vessels in U. S. waters.

THE OMEGA NAVIGATION SYSTEM:

OMEGA is an extension of LORAN technology. During the 1940s and 1950s, investigations of VLF navigation signals indicated that very long range navigation fix accuracy might be feasible due to inherent signal phase stability and the low attenuation of signals at transmission frequencies below 40 kHz. The system concept was validated through an R&D program begun in 1967. It demonstrated the feasibility of a world-wide navigational system, comprised of eight stations operating in the 10-14 kHz band with a nominal radiated power of 10 KW, that would be an adequate, general purpose aid to navigation for U. S. military use while providing civilian maritime facilities. Multilateral technical conferences are scheduled each year to discuss matters of mutual concern and interest.

The established operational goal for OMEGA system reliability/availability for navigation is a minimum of 95 percent. This can be accomplished through a comprehensive engineering program to maintain and upgrade system equipment and a long-term, continuous evaluation program to analyze system component performance. The upgrading program will provide substantial improvement in the station's electronic equipment reliability through a series of changes/modifications to the timing and control and transmitter equipment, which will also allow some degree of automation and reduced maintenance expense. Electronics equipment performance has been monitored since 1975 to develop a data base on critical problem areas, optimized preventive maintenance procedures at the station level, and level of spare parts stocking.

System calibration involves a rather complex set of procedures to determine accurately the behavior of received OMEGA signals on a world-wide basis throughout the year. Existing charts, lattice tables, propagation correction tables and other documentation must then be improved and provided to users so that they may realize the inherent accuracy of OMEGA as well as understand the limitations of the system. This process involves a two-step procedure. First, fixed worldwide monitor stations will be deployed permanently by the end of 1979 to collect, process and analyze data. These will be used to develop and publish (through DMAHC) more accurate predicted propagation corrections. Secondly, the permanent monitors will be temporarily supplemented by additional fixed and mobile monitors to collect more extensive data in specific areas of the world. Once the data is reduced, it will be used to establish the OMEGA coverage and accuracy within the surveyed area. This program is being conducted in annual increments, beginning with the Western Pacific in 1978 and ending with validation of the Indian Ocean/South Pacific area in late 1981 or early 1982. Some additional measurements in previously validated areas will be required to confirm or adjust predicted changes in system performance when OMEGA Australia becomes operational. At this time, it is apparent that some marginal coverage and degraded accuracy will occur after the final configuration is complete.

The user documentation work covers the plans and procedures for providing better charts, tables, propagation corrections and other documentation to meet the basic needs of the OMEGA user/navigator. DMAHC now provides charts to DOD and civilian users through standard requisitioning procedures. Lattice tables are tabular counterparts to the OMEGA charts, enabling the navigator to construct any line of position (LOP) on any chart or plotting sheet within the area of OMEGA coverage. A five-year plan (1975-1980) is underway to develop charts for DOD needs. The Coast Guard and NOS have had preliminary discussions concerning supplemental charting for civilian use, but no program has been developed nor specific tasks established. A Propagation Correction (PPC) model has been established for the frequencies 10.2 kHz and 3.4 kHz. Phase correction-models for 11.33 kHz and 11.05 kHz will be developed in the near future. To round out the user documentation, an OMEGA user handbook is being developed to explain the basics of OMEGA. Work is also underway to publish an initial system technical specification describing signal characteristics such as format, pulse rise and decay times, and accuracy of synchronization. This specification or standard will assist have been substituted wherever feasible and cost effective.

The Lighthouse Automation and Modernization Program (LAMP) will convert 104 light houses to complete automation by 1981. Sixty-four were completed by early 1978. System output will be incrementally improved by the low-budget application of new technology such as fast water buoys, natural energy sources (solar) to power aids, new concepts in the display of light signals, solid-state flashers for buoy lanterns, new buoy paint compounds, less noise-polluting sound signals, and better aids to navigation positioning methods.

A program has been initiated to improve the effectiveness of selected visual aids to navigation, when they are used as reference points for radar navigation. To enhance their detection and identification on a radar scope, some additional swept-frequency radar beacons (RACONs) will be installed on selected fixed and floating aids which are most useful to the radar navigator, particularly near harbor approaches. In the future, fixed frequency RACONs offer the potential for significant improvement with state-of-the-art technology. Adoption of this RACON type, however, is dependent upon international agreements on technical parameters of fixed-frequency RACONs (by the International Telecommunication Union) and on the modification or replacement of existing ship radars (by the Inter-Governmental Maritime Consultative Organization).

Future Developments.

The environment and technology of navigation are especially dynamic. Hence, there is a critical need to monitor the external technical, institutional, operational and economic factors affecting the selection and implementation of navigation systems; interact with the environment to shape and influence the future; and to conduct a research and development program to capture the benefits of the evolving science. Several technical papers will be presented subsequently giving the details of our work in this area. This paper is therefore limited to a summary overview of several specific issues:

(a) Development of an aids to navigation performance model.
(b) Loran-C development for HHE navigation.
(c) Loran-C use for non-marine applications.
(d) Navigation as an element of traffic management.
(e) GPS application to civil marine use.
(f) Radio navigation systems consolidation.

A major research project has been initiated to obtain a meaningful representation of the process of navigation under conditions of normal and reduced visibility. Specifically, what information is provided by aids to navigation within a given environment and how it is perceived and used by the mariner in directing the safe movement of the vessel, are questions that will be addressed. Basically, it will allow the development of an ability to define quantitative relationships between the aids to navigation system and the accuracy with which the ship can be navigated, especially in restricted waters where marine navigation is a dynamic, "man-in-the-loop" process which cannot be represented completely by mathematical models of purely physical processes.

The efficiency of Loran-C transponders as a supplemental method of surveillance in VTS harbor areas is being explored. Current use of radar and closed circuit television has, to date, been the primary method. Implementation will depend, to a large degree, upon the results of a current research and development project in Prince William Sound, Alaska and San Francisco. Shipboard Loran-C transponders will transmit Loran-C position information from TAPS tankers to the Coast Guard vessel traffic center in Valdez. Installation of test units will be completed by the end of 1978.

Extensive developmental work has been accomplished under DOD auspices to implement the NAVSTAR Global Positioning System (GPS). The Coast Guard intends to develop the basis for the effective use of GPS for civil maritime navigation purposes, thereby exploiting a potential national resource of major importance in facilitating the safe and expeditious passage of maritime commerce. While there are lingering questions concerning civil access to the system and achievable accuracies, the R&D plan is being formulated on the assumption that GPS will be implemented and will perform substantially as envisioned by DOD. The assumed accuracy for civil navigation is 1/4 NM (2 drms) at worst.

The Coast Guard input will be part of a DOT-wide GPS R&D plan, and will be coordinated with developmental activity underway in other Federal agencies. It is expected that the main thrust of Coast Guard effort will be towards low cost receiver development for high seas and CCZ areas. Development work which envisions a higher available GPS accuracy (i.e., HHE region) will be deferred pending a clarification of U. S. Government policy.

The emergence of GPS introduces a considerable perturbation in the evolution of radio navigation systems. Ultimately, in the post-1985 time frame, it is possible that some existing navigation systems will be progressively phased out after the NAVSTAR GPS becomes operational. It is uncertain as to what precise impact this will create for civil users. There has been considerable interest in the Congress and Executive Branch in the consolidation of radio navigation systems in the light of the potential availability of GPS, and for possible alteration of the traditional roles of Executive agencies for radio navigation systems planning, development and operation. The Coast Guard is participating in studies looking to resolution of the myriad questions that have been posed, and will seek to insure that the interests of civil maritime users are safeguarded.

Conclusion.

The world of maritime navigation is in a state of flux. The traditional separation of transportation modal requirements and planning is being bridged by new fiscal, political and organizational realities. Technology provides the driving force for improvement, and sometimes moves ahead of the capabilities of the society to manage efficiently and effectively. The Coast Guard seeks to adopt a posture of "adaptive forward planning" for its navigation systems, wherein incremental improvements and modifications can be made to a fixed framework of existing systems and procedures. However, policy and plan formulation must be subservient to broader national goals and fiscal constraints, which are variable over time and thus fluid and imprecise. Therefore, the plans must be regarded as accurate reflections of present intentions, but not necessarily as true indicators of final choices.

SESSION III
APPLICATIONS FOR NAVIGATION SYSTEMS

Chairman
George Haroules, Chief
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NAVIGATION SYSTEMS AND URBAN MASS TRANSPORTATION

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NAVIGATION SYSTEMS AND URBAN MASS TRANSPORTATION

by
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ABSTRACT This paper describes a communications system which incorporates location information and a data processing system to exercise command and control over land based vehicles. The Urban Mass Transportation Administration and the Transportation Systems Center are developing such a system for use by urban transit and paratransit organizations. The system also has application to other vehicle fleet operators. Location information can be generated in several ways. The harsh, urban, electro-magnetic environment can adversely affect location determinations, thus, tests of competitive location subsystems were made prior to selecting a contractor to develop the system.

Navigation is defined as the method of determining position, course and distance traveled over the surface of the earth by the principles of geometry and astronomy and by reference devices designed as aids. Modern technology has placed great emphasis on the use of these aids to achieve accurate position fixing; but the purpose, nevertheless, remains the same -- to ascertain the position of the person performing the determination.

Let me digress for a moment and talk about urban mass transportation -- then I'll return and try to put navigation and urban mass transportation together and see how the former can help the latter.

Urban mass transportation represents a means of transporting large numbers of people throughout an urbanized area. Public mass transportation is now expected to accomplish a number of things which will help to improve the quality of urban life. Among these are:

- increase the share of total trips borne by mass transit, thereby reducing fuel consumption and improving air quality;

factors, etc., are needed by transit system planners and schedule makers to adequately plan routes. Once collected, this data must be periodically updated so the service level can be adjusted to ridership trends. To give some prospective to the size of the data collection problems, let's take a look at the Southern California Rapid Transit District in Los Angeles. This is a rather large transit property, as the following statistics show:

Total number of buses operated	2,621
Number of routes	214
1-way route miles	4,294
Total annual bus miles	103,000,000
Total annual passenger trips	315,000,000
Service area (sq. mi.)	2,280

As can be imagined, planning service for such a transit property is a monumental task, requiring large amounts of valid data. Data collection, using manual procedures, is an expensive undertaking when one considers that the cost of one employee (including salary, fringe benefits and overhead) exceeds $20,000 annually. Additional costs are incurred in processing and analyzing the data. Due to pressures to minimize operating costs, many transit properties collect only small amounts of data, thus reducing the effectiveness of their planning efforts. Obviously, if the necessary data can be collected and processed automatically, with a minimum of effort, then larger, statistically valid sample sizes can be collected at low cost. If real-time data is collected, it can be used for additional operations.

In addition to reducing data acquisition costs, real-time vehicle performance data can be used to control vehicle fleets if it is presented to a dispatcher or fed into a computer. The development of vehicle fleet command and control systems, which is made possible by presenting a central dispatcher/computer with real-time vehicle information, can be expected to have a great impact on fleet operations.

The presentation of information on vehicles dispersed throughout an area to a central dispatcher/computer is what differentiates navigation (in the classical sense) from a command and control system. While the position determining equipment may be the same in each case, the presence of a communications system to transmit information vastly changes how the information is used and may result in unprecedented benefits accruing to the user.

The Urban Mass Transportation Administration (UMTA) and the Transportation Systems Center (TSC) are developing such a system under the Automatic Vehicle Monitoring Program. Details of this system will be presented by Mr. Bernd Kliem of TSC in his talk. One important comment concerning the UMTA/TSC AVM system must be emphasized — the AVM system is a communications system using navigation-type inputs (among other things); it is not a navigation system. In this system, navigation or location inputs are used to control vehicles and better manage the fleet.

With the knowledge that at least one location technology possessed sufficient accuracy to be useful to the fleet vehicle command and control situation, UMTA, in 1974, embarked on a program to develop and evaluate a fully functional transit-oriented command and control system. To this end, TSC was requested to be the systems manager for the program. Much study went into the development of the program; its objectives, requirements and expected benefits were analyzed. One output of this study was that a high level of accuracy was necessary to realize the benefits of such a command and control system when applied to the transit situation. Further analysis documented the need for a 300-foot accuracy level (95% of the time and 450 feet 99.5% of the time). In addition, the location subsystem would have to identify a bus' time of passage past known points to within 15 seconds (95% of the time, 60 seconds 99.5% of the time). A detailed statement of work was released which divided the AVM program into two phases. Phase I would test several location subsystems in Philadelphia. In Phase II, one contractor would be selected to continue and to develop and install the full system in Los Angeles.

After a detailed study of proposals received in response to the RFP, four contractors were selected to test their location subsystems. All tests were strictly monitored by government observers to ensure the validity of the data. Each contractor was permitted to "edit" his raw location data, if the processing software could automatically identify and reject erroneous data. The test results are shown in Table II.

Based on these test results and a re-examination of each Phase I contractor's test results, Gould Information Identificaton, Inc., was selected as the Phase II contractor.

One of the most important aspects to the Phase II program is the evaluation to quantify AVM's benefits. Much has been written and said concerning the expected benefits but little quantification has taken place. A study of the benefits and costs of AVM which was performed by TSC, indicates that benefit/cost ratios of up to 7 to 1 are possible for fixed route transit operations and up to 13 to 1 for police operations. While these results are based on analysis, rather than observation, they do indicate that the potential payoffs of such systems are indeed great.

LORAN-C AND OMEGA IN AVIATION

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LORAN-C AND OMEGA IN AVIATION

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ABSTRACT. This paper reviews the Loran-C and Omega navigation systems and their present status. Products of the FAA Loran-C and Omega development program and progress to the present are described. The specific technical approaches for several current projects are described in some detail.

I. BACKGROUND.

A. LORAN-C.[1] Loran-C is a pulsed, hyperbolic system, operating in the 90-110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of RF energy radiated by a chain of synchronized transmitters which are separated by hundreds of miles. The usable coverage from a Loran-C chain is determined by rated power of the stations, atmospheric noise, geometric relationship of the stations, and the specific capabilities of the receiver. The effective groundwave range from individual stations is typically 600 to 1,400 NM over sea water and depends on station power and the capability of the receiver. Measurements are made of a zero crossing of a specified RF cycle within each pulse. Making this measurement early in the pulse assures that it is made before the arrival of the corresponding skywaves. Precise control over the pulse shape ensures that the proper comparison point can be identified by the receiver. To prevent skywaves from affecting measurements, the phase of the 100 kHz carrier of each pulse is changed in a predetermined pattern. The nominal coverage area is based upon the assumption that the receiver being used can acquire and track Loran-C signals when the signal-to-atmospheric noise ratio is at least 1:3.

The Loran-C propagation mode most frequently used for navigation is the groundwave. Skywave navigation is feasible but with some loss in accuracy. Although it is designed for use, and normally operated in the hyperbolic mode, Loran-C can be used to obtain accurate fixes by determining the range to individual stations. This is accomplished by phase comparison of the station signals to a known time reference to determine propagation time, and therefore range from the stations. This is referred to as the range-range (rho-rho) mode. It can be used in situations where the user is within reception range of individual stations, but beyond the hyperbolic coverage area. This method of using Loran-C requires that the user have a very precise and stable time reference. The high cost of equipment of this type limits the use of this mode.

B. OMEGA.[1] Omega is a VLF (10-14 kHz) navigation system comprising at present seven of eight planned transmitting stations situated throughout the world. They provide usable signals over about 90 percent of the earth. Existing stations are in Norway, Liberia, Hawaii, North Dakota, La Reunion, Argentina, and Japan. Continuously available near worldwide position coverage will be attained when the eighth permanent station in Australia becomes operational in 1980. Omega generally utilizes phase comparison of skywave from pairs of stations to form hyperbolic lines-of-position. The stations transmit time-shared signals on four frequencies: 10.2 kHz, 11-1.3 kHz, 13.6 kHz, and 11.050 kHz, and each station also transmits a unique frequency (Figure 1). The purpose of the four time-shared frequencies is to permit some uncertainty in knowledge of the location of the Omega receiver when it is initialized. By calculating differences between transmitted frequencies through phase measurements, the artificial frequencies of 3.4 kHz, 1.133 kHz, and 0.283 kHz can be created in the receiver. With the artifically created frequencies and the transmitted signals a position uncertainty of ±267 km (±144 nautical miles) can be resolved by the receiver and the correct position determined. The unique frequency transmitted by each station is intended for use as an additional and unambiguous source of information for navigation. At present, operational avionic units do not yet make use of the new 11.050 kHz time-share frequency or the unique frequencies.

In the Omega system, ambiguous lines-of-position occur as there is no means to identify particular points of constant phase difference, which recur periodically throughout the coverage area. The area between lines of zero phase difference are termed lanes. Single frequency receivers use the 10.2 kHz signals whose lane width is about eight miles on the baseline between stations. Three-frequency receivers extend the lane width to 133 km (72 NM), but these are more expensive than single frequency receivers. Because of the lane ambiguity, receivers must be set to a known location. Once set to a location, the Omega receiver counts the number of lanes it crosses in the course of a flight. This lane count is subject to errors which may be introduced by an interruption of power to the receiver, changes in propagation conditions near local sunset and sunrise, and other factors.

The inherent accuracy of the Omega system is limited by the propagation corrections that must be applied to the individual receiver readings. The corrections are calculated and applied automatically in computerized receivers. The system is designed to achieve a predictable accuracy of 3.7 to 7.4 km (2 to 4 NM) (2-drms). This depends on location, station pairs used, time of day, and validity of the propagation corrections. The design repeatable accuracy is 1 to 2 NM (2-drms).

Propagation corrections are based in part on theory and modified to fit monitor data taken over long periods for localized areas. An extensive monitoring program is being undertaken by the Coast Guard under the aegis of the Navy which is managing overall implementation of the system. The monitor network will be used to verify the propagation model used to predict the corrections and the system accuracy in the area of the network stations. A number of permanent monitors will be maintained to update the model on a long term basis. Preliminary test data obtained in the operational environment have indicated that performance will satisfy the existing requirements

VLF noise cancellation antenna system, (2) development of an Omega/VLF signal monitor to provide an advisory service,[6,7,8,9] (3) evaluation of a combined INS/VLF system (report due Sept. 1978), (4) a program to collect and analyze Omega signal stability and interference near selected airport approaches, and (6) flight evaluation of state-of-the-art Loran-C avionics.

As noted above, three different Loran-C receivers were evaluated by three airlines to determine acceptability as a replacement for Loran-A. The evaluations were conducted in the North Atlantic, the Caribbean, and the North Pacific areas. Conclusions were that Loran-C would be a satisfactory substitute for Loran-A where usable signals were available. Airlines have chosen not to use Loran-C as a Loran-A replacement.

Prior to beginning hardware development for the Omega/VLF signal Monitor System, a study was carried out to define that system. Involved in the study was a theoretical evaluation of both VLF communication and Omega signals over the continental U.S., the North Atlantic, and Alaska. Also involved in the study was an analysis of possible navigation errors related to airways structure and navigation requirements. Following completion of the study, an agreement was entered into with the Naval Ocean Systems Center in San Diego to assemble an Omega/VLF Monitor System. In April 1978, the initial, Omega only, version of the Monitor was delivered to NAFEC for preliminary evaluation. The VLF monitoring capability will be added to the unit, and the complete Monitor system will be returned to NAFEC for final evaluation in March 1979.

The 3.4 kHz Omega receiver evaluation noted was with a specially modified Canadian-Marconi Model CMA-740 receiver that could navigate in either the 3.4 kHz mode or in the more conventional three-frequency hyperbolic mode. The 3.4 kHz is an artificial frequency derived from the difference between the transmitted 10.2 kHz and 13.6 kHz signals. It was expected that the 3.4 kHz receiver would have some immunity to Omega signal phase anomalies and would be less likely to acquire position errors known as "lane slips." Results indicated somewhat better performance in the conventional three-frequency mode than in the 3.4 kHz mode. The Omega flight test program mentioned was in Alaska with a prototype low-cost receiver (i.e., $6,000). It was found to have a high pilot workload, but might be suitable for use by many civil aviation aircraft.

In another effort a study was made to validate the civil air navigation requirements for CONUS, offshore and Alaska. A requirements matrix (Figure 2) was developed to provide a common basis for defining the requirements across all the geographic areas considered. The second basic objective of the study was to assess the capability of Loran-C, Omega, differential Omega, and VLF communication signals toward meeting the requirements. Loran-C was found to offer all-altitude coverage for all geographic areas given signal coverage from existing and proposed chains. The primary drawback is the large area and, hence, the number of aircraft affected by a single station outage. With suitable redundancy Loran-C might meet the civil air navigation needs. Omega lacks adequate signal coverage over the continental U.S. Therefore, Omega is a candidate only in Alaska, and in offshore areas. The VLF communications system is not dedicated to navigation, accuracy questions. Signal stability measurements will be made with a specially equipped test van throughout the Eastern United States. Equipment in the van will include an Austron Model 5000 Loran-C receiver, a Hewlett-Packard spectrum analyzer, and recording equipment. Signals will be monitored at various locations to include the normal airport environment, urban areas, and mountainous area. Specifically, measurements will be made in Washington, D. C., Baltimore, Philadelphia, and New York City, to determine the Loran-C signal situation amid the possible interference generated by large cities. The mountainous areas to be investigated are Rutland, Vermont; Blackburg, Virginia; and Dunkirk, New York. Airport environment measurements will be made at NAFEC. Sites at which measurements will be made were selected by a separate study. In addition to long term ground measurements, a program for Loran-C flight evaluation will be carried out by the FAA over a broad geographic area. A more specific evaluation will be conducted in cooperation with the State of Vermont within that State.

Loran-C avionics to be used in the flight tests will be the Teledyne Models TDL-424 and TDL-711. The TDL-424 is the more sophisticated system and should show the better performance. To be added to the program will be the measurement of possible interfering signals from commercial power lines. Some power companies are using radio frequency carriers transmitted along their lines to regulate loads by remote control switching. Some of the frequencies used for remote switching are in the 90 kHz to 110 kHz Loran-C band. Potential interference by other radiating sources near the Loran-C band (e.g., Navy Communications) and self-interference by undesired Loran-C signals may also be examined.

System reliability is of great significance expecially to the general aviation operator using a low cost Loran-C receiver. It is possible that such a low cost receiver would operate only from signals from one Master Station and two specific secondary stations. The failure of any one of the three stations would eliminate his radio navigation service. Additional capability in the airborne unit would somewhat alleviate the problem, but cost would increase. Accuracy measurements will be made during flight tests at the National Aviation Facilities Experimental Center in New Jersey, and during the planned flights in Vermont.

B. OMEGA. There is a need to increase knowledge of Omega signal availability and reliability over most of the major oceanic air routes. This knowledge is needed to support decisions regarding the increasing use of Omega, and also support development of an effective system advisory service. The planned program includes the following steps:

(1) Procure digital data tape cassette recorders.

(2) Secure participation in the program by air carriers with Omega receivers installed.

(3) Lend recorders and a supply of tape cassettes to each of the participating organizations for installation in their aircraft.

(4) Establish a data analysis and reporting capability at NAFEC for processing of the data on the tape cassettes.

(7) E. R. Swanson and J. E. Britt, Naval Electronics Laboratory Center, "VLF Navigation Monitor: Engineering Design," U. S. Department of Transportation, Federal Aviation Administration, Washington, D. C., June 1975, FAA-RD-75-148

(8) E. R. Swanson, Naval Electronics Laboratory Center, "VLF Navigation Monitor: Purpose and Function," U. S. Department of Transportation, Federal Aviation Administration, Washington, D. C.

(9) E. R. Swanson and M.J. Dick, Naval Electronics Laboratory Center, "Propagational Assessment of VLF Navigation Signals in North America and the North Atlantic," U. S. Department of Transportation, Federal Aviation Administration, Washington, D. C., February 1975

(10) F. Karkalik and E. Wischmeyer, Systems Control, Inc. (VT), "An Operational Evaluation of Omega for Civil Aviation Oceanic Navigation," U. S. Department of Transportation, Federal Aviation Administration, Washington, D. C., February 1977, FAA-RD-77-65

(11) F. Karkalik, Systems Control, Inc. (VT), "Loran-C, Omega, and Differential Omega Applied to the Civil Air Navigation Requirements of CONUS, Alaska, and Offshore," U. S. Department of Transportation, Federal Aviation Administration, Washington,D. C., April 1978, FAA-RD-78-30-I, II, III (three volumes)

LORAN-C CAPABILITIES FOR HIGHWAY TRAFFIC SAFETY APPLICATIONS

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LORAN-C CAPABILITIES FOR HIGHWAY TRAFFIC SAFETY

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LORAN-C capabilities are explained with respect to serving highway traffic safety programs and functions. The LORAN-C applications of Automatic Vehicle Monitoring, Dispatch and Position Location are defined and discussed. These applications have a real potential for satisfying the navigation needs of the highway safety programs of Traffic Records, Emergency Medical Services, Police Traffic Services, Highway Inventories and Highway Maintenance.

I welcome this opportunity to address the representatives of the DOT Conference on Navigation. This is a special honor when you stop to consider that our highway safety applications cannot actually be classified as navigational techniques in getting from point A to Point B, but rather as adaptations which take advantage of the fringe benefits available from the LORAN-C system of radio navigation.

As you know, LORAN-C was designed for use primarily within the coastal water boundries of the United States, but its inherent property of transmitting nondirectional radio waves provides the same precise locating capabilities over surrounding land areas as are available over coastal waters. Thus, utilization of LORAN signals over land areas, in highway traffic safety applications, is considered a bonus by-product of the LORAN-C System.

In recognition of LORAN-C's potential land applications, the National Highway Traffic Safety Administration (NHTSA) and the Federal Highway Administration (FHWA) - both agencies of the U.S. Department of Transportation - have initiated demonstration projects to evaluate the utilization of LORAN-C's basic functional capabilities in various aspects of on-going highway traffic safety programs.

APPLICATIONS

We have identified three major LORAN-C applications that have great potential for satisfying operational needs of highway traffic safety programs. These are:

be confusing if there is a Magnolia Avenue, Magnolia Place, or Magnolia Court all located in the same community. And how do we resolve the variations in different methods of position location referencing when these methods all describe the same "address"? For example, take the following four descriptions of the same location:

- on a state road map it would be near the intersection of routes U.S. 50 and 522 or

- about 10 miles southeast of Winchester, Virginia, or

- between mile markers 101 and 102 on Route 50, or even

- a couple hundred yards down from Mike's garage.

And yet, as ambiguous as these references are, they are still less problematic than trying to determine the position of a moving vehicle.

One of LORAN-C's more unusual attributes is the way in which its location coordinates lend themselves to computerized storage and retrieval. Naturally, as an aid in position location, the LORAN-C generates information concerning the rather specific location of an object or event. The information generated is purely numeric; no narratives of any type are involved in LORAN-C's position descriptions. And because numbers can be stored easily and efficiently in automated form, LORAN-C's data is tailor made for computer storage, and for automated retrievals.

Since the data is purely numeric, there can be none of the ambiguity that might result from attempting to retrieve narrative descriptions. When a user wants to retrieve the location of a position which has already been identified, he does not have to cope with the possibility of obtaining a very similar address, which might be the case if he were dealing with narrative data. In other words, there is no possibility of retrieving "10 Magnolia Court" when one really wanted "10 Magnolia Road", because with LORAN-C references these two locations would be identified by two entirely different sets of numbers.

There's another advantage to using LORAN-C for location description and that is its repeatability. In other words, if you can find something once using LORAN coordinates, you can find it again, with perhaps only a small margin of error. This is often not the case when you are trying to find a location which has been described by narrative. For example, take the case of a traffic accident occurring on a stretch of a rural Nebraska highway or on an unmarked rural road. How can a traffic enforcement officer report the accident's location other than in words? And without any definitive or close-by landmarks, how can investigators find the precise spot once the accident has been reported? Problems such as these are eliminated when LORAN-C coordinates are used to describe the location. With this method, repeatability of results is no longer a matter of luck, with LORAN-C, it's guaranteed.

EMERGENCY MEDICAL SERVICES

Vehicle Monitoring and Dispatch: Position Location

States presently conduct different types of highway inventories, including Point Type inventories, which are listings of such features as bridges, signs, traffic control devices and railroad grade crossings, and Length Type inventories, which consist of sufficiency/needs inventories, design characteristics and photo-logging. These different inventories would benefit greatly from LORAN-C's location referencing capabilities. LORAN-C's position location capabilities could reduce the need for route mile-points, reference posts, logs and strip maps which are currently used in conducting highway surveys.

The system could also be used for roadway and roadside hazard inventories as well as for accident location. If we use LORAN-C coordinates for location identification, we can retrieve and cross-reference highway inventory and accident location data, so that roadway characteristics and roadway usage data can be displayed or printed together with accident histories.

HIGHWAY MAINTENANCE

Positive identification of road areas where maintenance is required could be made easier by identifying these areas with LORAN-C coordinates. Once these areas have been identified, vehicles which provide snow-plowing, moving, patching or debris removal services could be dispatched and their work could be monitored, and all of these activities -- identification, dispatching and monitoring -- could be accomplished with the LORAN-C system.

SYSTEM COMPONENTS

The four following components are required before LORAN-C can be applied to highway traffic safety.

1. LORAN-C Receiver

Until quite recently, cost was a prohibitive factor in the acquisition of LORAN receivers for highway traffic safety, but today, improvements in receiver technology have reduced unit prices.

Presently, LORAN receiver costs are based upon the number of units scheduled by the manufacturer for a given production run. This variable can cause a great deal of price disparity, but unit prices can be expected to fall within an average dollar range.

To make the use of LORAN-C receivers cost feasible for highway traffic safety, the unit price will have to be reduced to the $200 to $300 range.

2. Area Maps - (calibrated for LORAN-C)

Another cost must be considered before LORAN-C can be utilized on a wider scale, and that is the cost of amending existing maps to display LORAN-C coordinates. Maps for a specified locality are produced by calibrating the position location of the LORAN-C coordinates. Maps of the U.S. Geographical Survey Series quality would cost approximately $200.00 for the initial calibration of a 450-square-mile area. Subsequent modifications would be less costly.

THE FUTURE OUTLOOK

The Department of Transportation does not have a specific responsibility under law to provide radio location systems for land use as yet. However, under the general provisions for improving the safety and efficiency of transportation, a number of research, development and demonstration projects have been sponsored. And in support of this goal of safe and efficent transportation, there is nothing to prevent a prospective user from taking advantage of an operating navigation system.

There are a number of institutional constraints, however, which will have to be faced when the technological problems are overcome. The major constraint is inertia. Many of the agencies that would be involved do not readily change their operating procedures. Cost benefits, of the conversion would have to be proven. Availability of resources could also be a stumbling block. One major constraint against rapid deployment of a new system or termination of existing radio navigation services is the size of the investment by users and by the federal government. Any replacement system should be able to meet the requirements better and at a comparable or lower cost. It should also meet the needs of a broader spectrum of users, so that the total number of systems in use can be reduced. The transition period for implementing a new system could be ten or more years, but this period of time would assure proper implementation.

Before a full commitment is made, the following criteria should be met:

1. The system must meet design requirements.

2. User equipment at reasonable cost must be available.

3. The system must be acceptable to the user community.

AN EVALUATION OF RETRANSMITTED LORAN IN SAN FRANCISCO HARBOR

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AN EVALUATION OF RETRANSMITTED LORAN IN SAN FRANCISCO HARBOR

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ABSTRACT. The United States Coast Guard has performed a successful demonstration in San Francisco Bay of the feasibility of using retransmitted Loran-C data in monitoring vessel positions for the purpose of supporting Vessel Traffic Service (VTS) operations.

The experiment consisted of shipboard Loran-C receivers and associated telemetry units and a real-time minicomputer system driving a graphics display. The Loran-C telemetry units periodically and automatically transmitted the digital time difference data through a VHF-FM voice channel to the base station computer. Activation of voice transmission automatically inhibited the Loran-C retransmission. Upon receipt of time difference data, the base station computer converted those data into Latitude/Longitude and the X-Y coordinates, and displayed these vessel positions with identifiers and time tags against an appropriate segment of the San Francisco Bay map. The West Coast Loran-C chain of 9940 GRI (Group Repetition Interval) was used for this experiment with master station at Fallon, NV, and two secondary stations at Middletown, CA, and Searchlight, NV. Tests were conducted in those areas of San Francisco Bay where vessel surveillance has radar coverage such that both Loran-C and radar data on a vessel can be collected for later comparison and analysis.

In addition to the hardware configuration and software functions of this experimental system, this paper also describes briefly the conduct of the test and some qualitative presentations of some test data. The reduced raw data are still being analyzed by the Coast Guard R/D Office, which will release the test results in the near future.

INTRODUCTION

In response to the concern over the increasing number of marine casualties and ecological damages, Congress enacted the Ports and Waterways Safety Act of 1972 (PL 92-340). Among the provisions of this act is the authorization for the U.S. Coast Guard to establish, operate, and maintain Vessel Traffic Service (VTS) centers to improve marine safety and guide orderly vessel traffic movement. A VTS system has a number of basic elements which include a set of rules

The technical objectives of this experiment are threefold:

1. To characterize a Loran-C surveillance sensor system, a number of basic parameters, i.e., accuracy, stability/repeatability, and resolution will be measured. The quantity of these parameters cannot be measured in an absolute sense. However, they will be compared against those that are derived from a high-resolution radar.

2. To characterize the retransmitted Loran-C data from the participating vessel to the base station, three basic parameters will be measured, i.e., the transmission accuracy, the data update rate, and the channel utilization.

3. To assess the suitability of the retransmitted Loran-C as a VRS surveillance sensor, the minimum vessel separations detectable will be determined by statistically analyzing the collected data.

FIELD SITE ENVIRONMENT

The field site for testing is at the Vessel Traffic Center (VTS) situated on Yerba Buena Island in San Francisco Bay. Currently, the VTS houses two independent vessel traffic systems. One system is the operational system which serves the San Francisco maritime community on a twenty-four-hour-a-day basis. This system employing two radars, one at Point Bonita (PTB) and the other at Yerba Buena Island (YBI), has the coverage of a large portion of the San Francisco Bay and also for the approach into the bay. It relies on communication (VHF radio) between the individual ship's pilots and the control center. The other system, called a Sensor Tracking Test System, is a R/D tool designed for the evaluation of any surveillance sensor system under development.

Sensor Tracking Test System

The Sensor Tracking Test System consists of the Automated Vessel Traffic System, a Data Collect Computer, and a Sensor Systems under test.

Figure 2 is a block diagram of the Sensor Tracking Test System.

The Automatic Vessel Traffic System has a radar video preprocessor and a radar computer (DDP 516) to perform automatic detection and tracking (ADT) of the ships in the harbor. Another computer, the traffic computer (DDP 516), is interfaced to the radar computer and used to perform traffic analysis and display functions (TAD). Its man-machine interface is implemented by a display processor (IMLAC PDS-1) which is used to analyze watchstander service requests, communicate with TAD, and update graphical CRT displays.

Other hardware equipment includes the data collect computer (Interdata 732), a hard-copy unit, and a Tektronix 4010 display. Also, there is a Plan Position Indicator (PPI) and a PPI camera.

The function of the data collect computer is to record test data from both the Loran-C and the radar for subsequent data reduction. The data collect computer will also provide in semi-real-time a "quick look" capability, consisting of tabular data and plots of radar-detected vessel positions versus Loran-C vessel

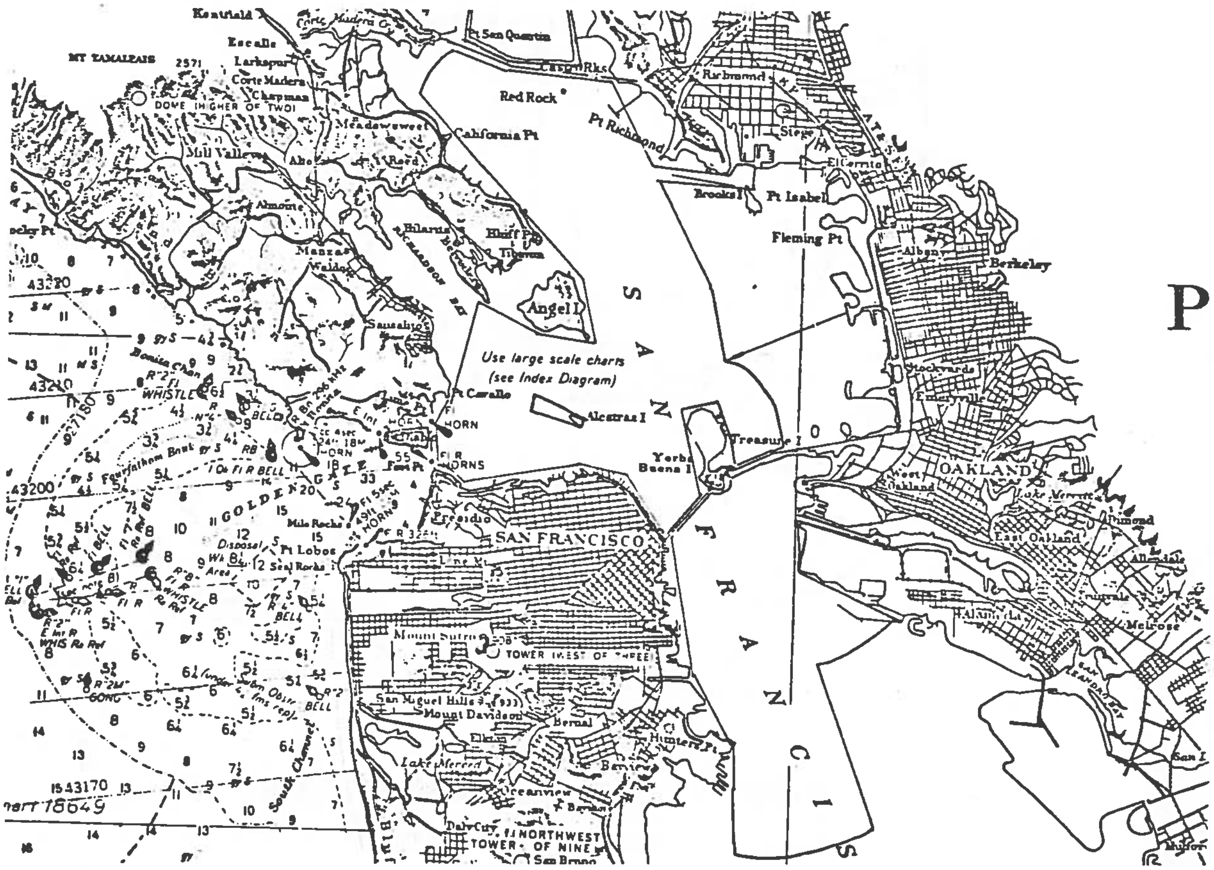


FIGURE 3 RADAR COVERAGE CHART

Loran-C Chain

The Loran-C chain which provides coverage for the San Francisco area is the U.S. West Coast chain (GRI = 9940), shown in Figure 4. Information on the location, coding delay, approximate distance from San Francisco Bay to each secondary station, and theoretical calculations of the gradient for each, are tabulated below:

STATION	Fallon, NV	George, WA	Middletown, CA	Searchlight, NV
LAT/LONG	39°33'6"/ 118°49'56"	47°3'48"/ 119°44'39"	38°46'57"/ 122°22'44"	35°19'18"/ 114°48'17"
CODING DELAY (usec)	MASTER	13,896.22	28,094.50	41,967.28
DISTANCE FROM SAN FRANCISCO (nm)		575	61	400
GRADIENT (ft/usec and deg. from north)		1252'/usec @ 124°	936'/usec @ 116°	1100'/usec @ 356°

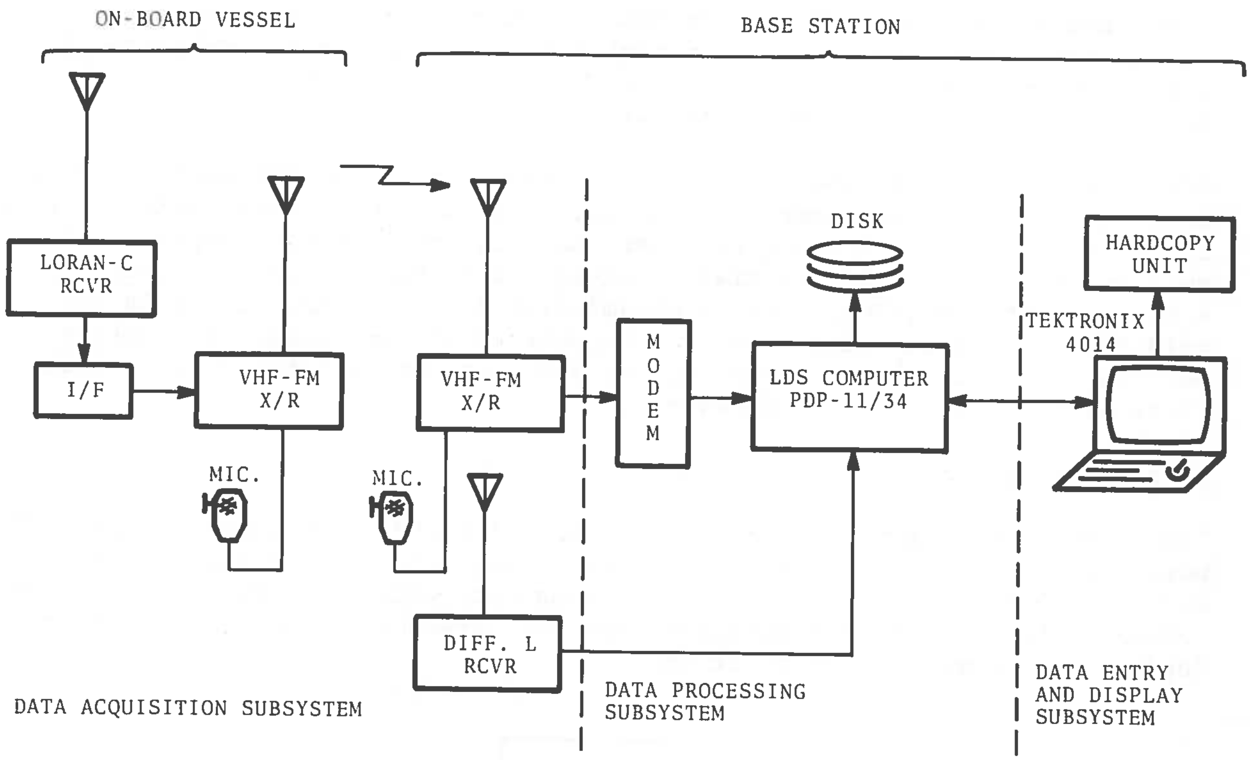
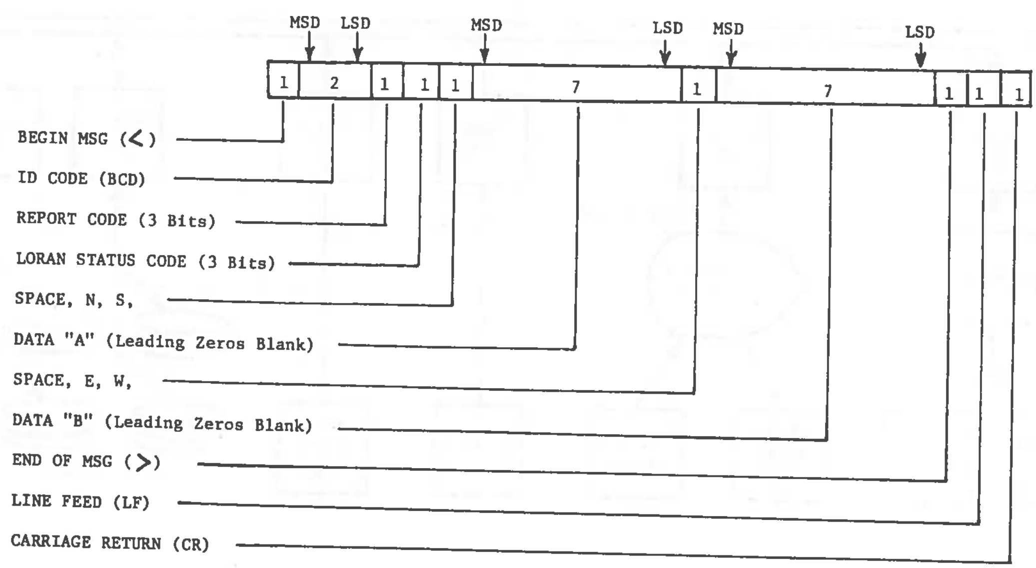


FIGURE 5 LDS BLOCK DIAGRAM



LEGEND: MSD - Most Significant Digit
LSD - Least Significant Digit

FORMAT: ASCII, 10 Bit
1 Start, 7 Data, 1 Parity, 1 Stop

STANDARD: BELL 202 tones
4 Cycles(1200 Hz = MARK 1)
7 1/3 Cycles(2200 Hz = SPACE 0)

MSG LENGTH: 24 chars.(0.8 sec)

BAUD RATE: 300 chars/sec

FIGURE 6 ASCII DATA LINK MESSAGE FORMAT

addition, the long-term average values of the time differences are computed from which correction factors of TDA and TDB will be determined and passed along to the Data Collect Computer.

The dynamic TD values, representing the current positions of vessels are converted into LAT/LON's which are in turn aligned with the X-Y areas of the displayed area map onto which vessel targets are displayed. Associated with each target is a leader and a fall data block which consists of the vessel ID and the time of reception of this position reading. The screen is updated once every 10 seconds with the most recent position information, thus simulating the movement of vessels in the bay against a background map.

Data Entry and Display Subsystem

The data entry and display subsystem uses a Tektronix 4014-1 display terminal with its associated keyboard and joystick. It also includes a hard-copy unit and an interactive buffer option. By using the keyboard, an operator can interact with the computer, instructing it to perform specific functions, with the computer's response being returned to that operator by way of the display screen achieving an interactive mode of operation.

LDS SOFTWARE FUNCTIONS

Graphic Capabilities

The following is a brief description of the functions that the Loran-C Display Software (LDS) will perform. The display software will accept digital messages from up to eight vessels which have a Coast Guard Loran-C telemetry unit installed on board. The digital messages contain position information which will be processed and displayed on a geographic map. These messages from each vessel will be stored on floppy disks in eight subfiles, each subfile denoting a particular vessel. A ninth subfile will contain erroneous messages.

NOAA charts (Mercator Projection) covering the San Francisco Bay Area have been digitized off-line and this information, together with software tables, pointers are stored on floppy disk. A display module provides for user definition of submaps with the San Francisco Bay region, which can be called by name for screen display. The system also provides for software zoom-in/zoom-out on these geographic maps. A file containing annotations of pertinent buoys, lighthouses and landmark identification was generated during map digitization and the software map select routine overlays these annotations as appropriate on the selected geographic presentation. In addition, the operator may make temporary annotations on the display, and delete them when they are no longer needed.

The Loran-C display has a number of additional features that relate to the position-monitoring function such as:

- Measure range and bearing.
- Determine latitude and longitude.
- Indicate a position by entering latitude and longitude.

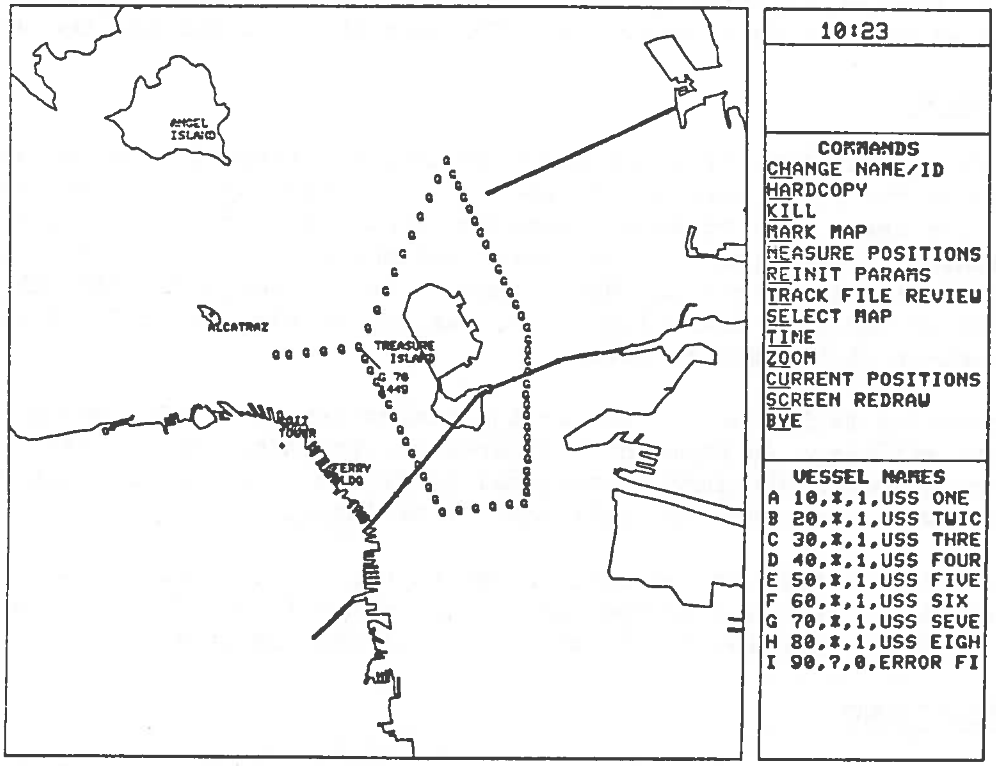


FIGURE 8 LDS DISPLAY FORMAT

display presentation. Similarly, the operator selects a subcommand by keying in its first two or three alphabetic characters, after which the carriage return is depressed. Again, the command process routine, if needed, writes additional "prompts" into scratch pad for use as operator aids. Subsequently, the command process routine completes its function and returns control to OCCI waiting for the next operator request.

CONDUCT OF TESTS

System integration at the Coast Guard Vessel Traffic Center on Yerba Buena Island began in the end of May 1978 for approximately two weeks. An important aspect of the system integration process is the site calibration where known benchmark locations were measured with Loran-C time differences which were used to calibrate the display map on the CRT screen.

Three vessels were used for the tests; 50-foot steel hull harbor tug from U.S. Army Corp of Engineers, and two smaller civilian pleasure boats whose owner in U.S. Coast Guard Auxiliary volunteered their services. Reflectors were used on those civilian vessels to facilitate radar track acquisition.

Static tests were conducted first by having one vessel anchored at a known benchmark location and a second vessel moored at a distance between 50 to 100 feet from the anchored vessel. Dynamic tests were carried out by having all three vessels running maneuvering patterns (one a square pattern and the other a triangular figure eight) of various dimensions. Throughout the test process,

NAVIGATION SUBSYSTEMS IN THE AUTOMATIC VEHICLES MONITORING (AVM) PROGRAM

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NAVIGATION SUBSYSTEMS IN THE AUTOMATIC VEHICLE MONITORING (AVM) PROGRAM

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ABSTRACT. Automatic Vehicle Monitoring (AVM) is discussed as a complete system with subsystem elements. The location subsystem design decisions for any AVM are presented, and bus transit as well as transit support vehicle location requirements are specifically addressed. The location subsystem aspect for the AVM deployment in Los Angeles is presented with emphasis on the hybrid design for the transit support vehicles. Overall system reliability/ maintainability concepts and estimated vehicle equipment costs are identified along with the approach taken for the AVM demonstration in Los Angeles.

AVM IN TRANSIT SYSTEMS

Automatic Vehicle Monitoring (AVM) encompasses a class of electronic systems that provide information and control capabilities for fleets of vehicles. Such a system automatically determines the status and position of each vehicle in the fleet. As part of the system, a central computer processes this information and permits optimum strategic deployment of the fleet, provides management information on fleet performance, allows for timely tactical fleet control decisions and enhances fleet security with a silent alarm capability. AVM as discussed here implies a system that has all of these functions. The payoffs from such a system for bus transit are in

- equipment (fewer vehicles required)
- management information (schedules, planning)
- security (reduced response time).

The near instantaneous information available through the computer/displays permits immediate tactical control decisions when fleet disturbances occur. Today these control decisions are made with or without fleet disposition information and rely, in the most modern systems, on radio/voice communications. For management data, teams of data collectors could laboriously collect information on selected routes. With the knowledge of vehicle location, aid can be dispatched to the specific position of any vehicle that has activated the silent alarm

SUBSYSTEMS IN AVM

An AVM system has three major elements or functional categories:

The specific signpost concept uses a broad radiation field. (Broad-field signpost types permit a separation between adjacent signpost units of 800-1200 feet.) LORAN-C was selected after a cost analysis indicated that for large metropolitan areas of over 500 square miles, assuming good LORAN-C coverage, a hybrid concept had cost-effective potential. From the location subsystem tests[4] conducted in Philadelphia, PA, it was clear that in high-rise areas LORAN-C signals are typically too weak or distorted to be used without signpost augmentation. In low rise areas, again assuming good signal coverage, LORAN-C could be used with little or no augmentation. The accuracy of LORAN-C derived information is a strong function of signal-to-noise ratio and geometrics of the chain. For the Los Angeles application, predesign studies and an initial LORAN-C signal survey have identified problems that need to be resolved before a hybrid design can be accomplished. These problems include:

- noise environment (severe in Los Angeles),
- receiver acquisition/reacquisition--settling times,
- influence of vehicle dynamics, and subsystem conceptual design for using additional location inputs.

From the preliminary LORAN-C signal survey conducted in the 30 square mile area around downtown Los Angeles, only about a 50 percent good signal coverage was observed. Although this percentage is expected to be more favorable in the low-rise areas, the data have not yet been taken. Acquisition and settling times of presently available commercial receivers are in the order of 2 to 5 minutes for reasonable signal-to-noise ratios (~0 dB and above.) These acquisition and lock-on times are typical for vehicles standing or moving up to 20 mph. For vehicles accelerating/decelerating or performing high velocity maneuvers, insufficient data on the dynamics of receivers exist. External aids to reduce these times will be required if LORAN-C is to be effective in urban AVM systems. In the urban environment vehicles frequently traverse underpasses or other regions of poor signal conditions. The question of oscillator stability to permit maintenance of receiver-lock through such areas clearly needs to be further examined. Anticipated requirements for short-term stability are about one part in 10^7. A design approach under investigation is to use signpost data (converted to LORAN-C coordinates on the vehicle) to update the LORAN-C tracking loop to reduce settling times.

One design tradeoff impacts another and the location subsystem decisions impact the communications subsystem. With the advent of better and less expensive microprocessors, on-board computations can be performed that will reduce the demand on communications. With the FCC requirement for 200 vehicles on each AVM channel along with a bandwidth of 20-25 kHz per channel, the vehicle interrogation and reply cycle permits each vehicle to be polled every 30 to 40 seconds. This indicates that an adaptable polling regime will be required to permit tracking of fast moving vehicles. Fortunately the number of fast moving vehicles in a composite fleet of 200 is quite small.

For any new system to be used it must perform its function in a manner that gives the user confidence that decisions based on inputs provided are not incorrect. This is especially true for the command/control (tactical) and safety (silent alarm) aspect of the system application. For the management information aspect, usually enough data exists to cull any questionable data points and still provide statistically valid outputs. However, to

2. B.E. Blood, "Experiments on Four Different Techniques for Automatically Locating Land Vehicles," U.S. Dept. of Transportation, Transportation Systems Center, Cambridge, MA, UMTA-MA-06-0041-77-2, November 1977.

3. G.W. Gruver, "A Comprehensive Field Test and Evaluation of an Electronic Signpost AVM System," Vol. 1: Test results, Hoffman Information Identification, Inc., Fort Worth, TX, UMTA-MA-06-0041-77-8, August 1977.

4. R. Stapelton, "LORAN Automatic Vehicle Monitoring System, Phase I," Vol. 1: Test results, Teledyne Systems Company, Northridge CA, UMTA-MA-06-0041-77-10, August 1977.

LORAN-C FLIGHT EXPERIMENTS FOR THE STATE OF VERMONT

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LORAN-C FLIGHT EXPERIMENTS FOR THE STATE OF VERMONT

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ABSTRACT. An overview of the Loran-C flight experiment project in the State of Vermont is presented. The experiment will be conducted to investigate the feasibility of using Loran-C for enroute, terminal, and non-precision approaches in the State Vermont.

INTRODUCTION

A Loran-C Flight Experiments project has been initiated by the Research and Special Projects Administration (RSPA) of the Department of Transportation. This project will determine the feasibility of using a Loran-C area navigation system in the State of Vermont. An overview of the project is presented in this paper which discusses present plans, the testing to be conducted, and the program schedule.

The Transportation Systems Center (TSC) will manage the project, with extensive participation by the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA/LANGLEY), and of course the State of Vermont. The role each agency plays will be discussed in the section on Project Definition, Participant Roles.

Loran-C is a hyperbolic radio navigation system. While designed for, and primarily used as a marine navigation system, Loran-C shows a great deal of potential for terrestrial and airborne applications. One such application is air navigation.

There has been some use of Loran-C for airborne purposes such as non-precision helicopter approaches, off-shore navigation and crop and forest spraying. The military and the Coast Guard have relatively extensive experience in the airborne use of Loran-C.

The use of Loran-C for general aviation navigation has been talked about and analyzed to some extent, but little or no experience or data exists for such Loran usage in a normal Air Traffic Control Environment.

PROGRAM OBJECTIVE

The objective of the Loran-C Flight Experiment investigation is not to weight

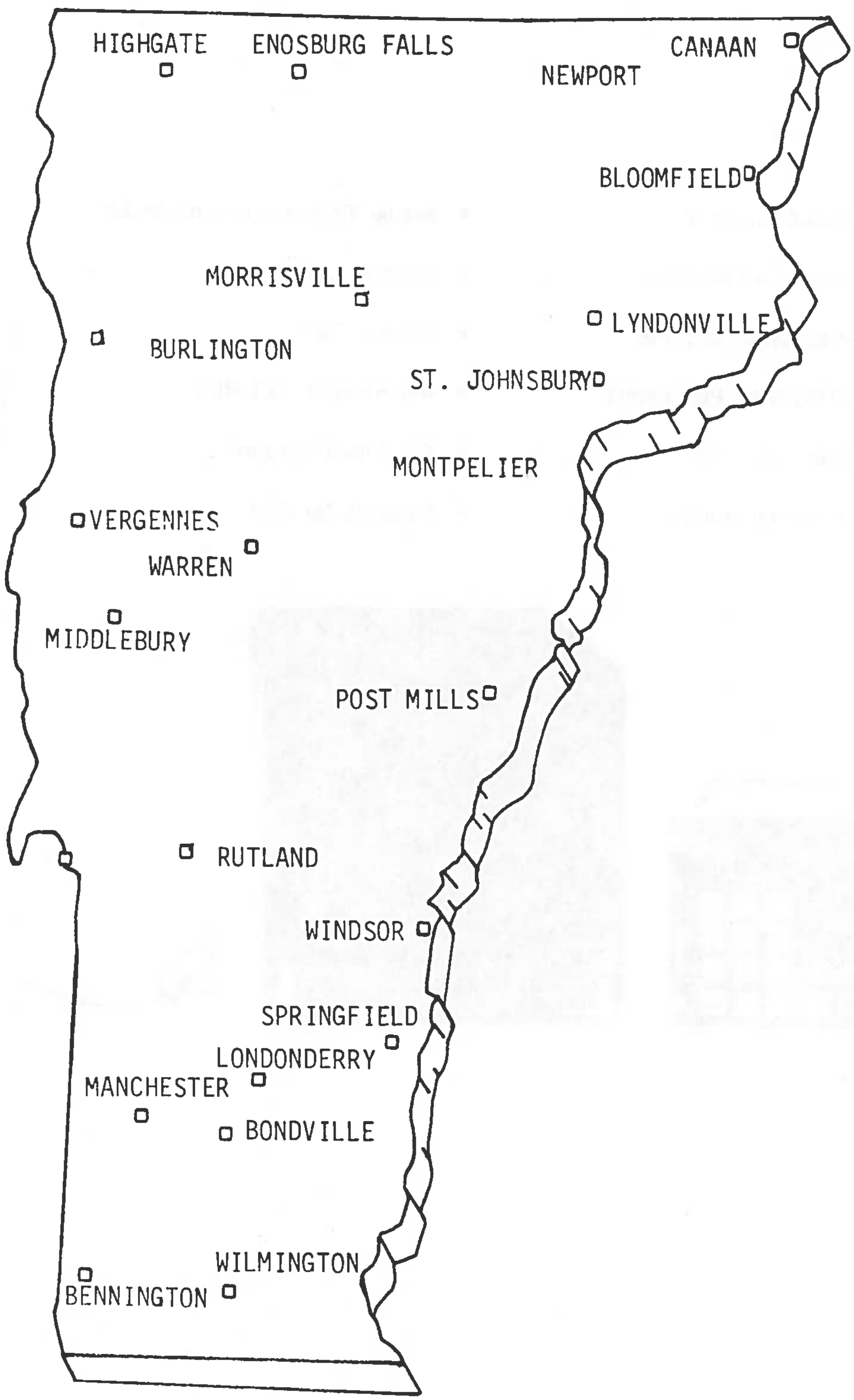
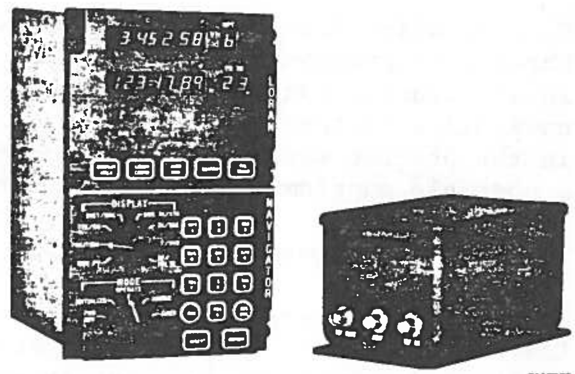


FIGURE 1. STATE OF VERMONT PUBLIC AIRPORTS

- Continuous position in lat/long or Loran
- 9 waypoints in lat/long or Loran
- Auto/manual leg sequencing
- Interwaypoint range and bearing
- Eleven stored Loran chains
- Optimum secondary pair advise
- Stored patterns and parallel track nav



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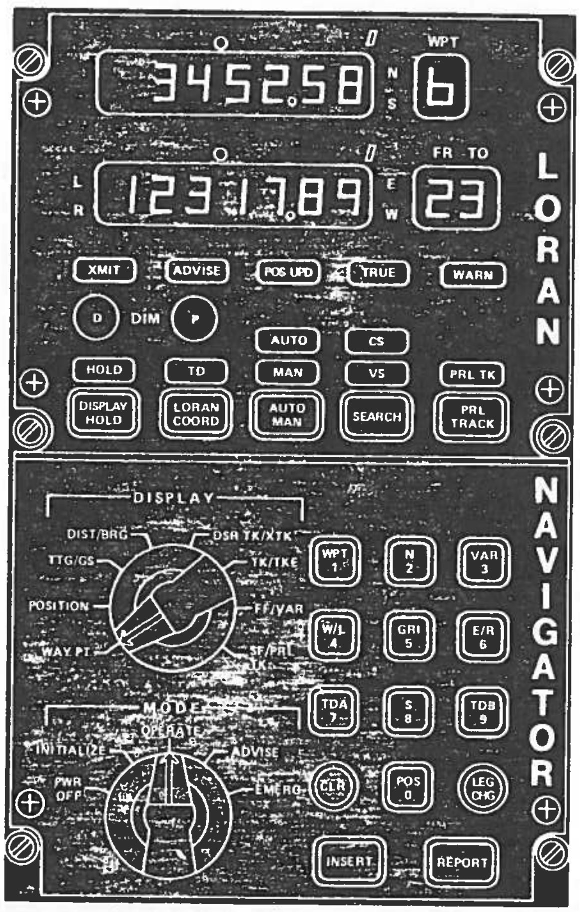

- Master independent operation – an industry "first"
- Position updating in lat/long, TD's or by waypoint
- Overfly position freeze and display hold
- Converts present position into a waypoint
- True or magnetic bearings
- Advise and warn functions
- System status advisory tableau
- Built-in test
- Telemetry of any displayed data (ASC II)
- Automatic and emergency data link reporting
- Analog autopilot and CDI outputs
- Digital data bus output (ARINC)
- Data link control of waypoints (optional)

FIGURE 3. TDL-424 LORAN NAVIGATOR SET

outages.

This data will be collected with the TSC Loran-C van and the NASA/LANGLEY Loran-C/Omega trailer, and time tagged such that any anomalies detected during flight tests can be correlated with conditions encountered on the ground.

The airborne tests will consist of two general types:

1. Accuracy Tests
2. Procedural and Operational Tests

ACCURACY TESTS

Accuracy tests are designed to determine whether Loran-C (Loran-C signal with a suitable receiver-navigation system) can meet existing requirements for 2D RNAV Systems. Typical of these requirements are those specified by the FAA's Circular for Approval of Area Navigation Systems for use in the U.S. National Airspace System (AC-90-45A). AC-90-45A currently requires that 2D RNAV systems not using VOR/DME for continuous navigation information must demonstrate that the total error contribution of the airborne equipment should not exceed the following with a 95% confidence over a period of time equal to the update cycle:

	Cross Track (nm)	Along Track (nm)
Enroute	2.5	1.5
Terminal	1.5	1.1
Approach	0.6	0.3

With the criteria spelled out by AC-90-45A used as a guideline, flight testing will be conducted by the FAA with the Convair 580, to collect comparison data to provide sufficient statistical results to determine the corresponding accuracy of Loran-C with the low-cost navigator system tested.

The technique to be used includes comparison of Loran-C derived position with VOR/DME where available, and comparison of Loran-C with a ground reference derived position. The ground reference system utilized consists of a triple DME system. The FAA will install the DME transmitters at surveyed sites, with the test aircraft position being determined by the three independent range measurements. Supplementary data will also be collected to compare performance of the TDL-711 with the TDL-424. The accuracy tests will be conducted by the FAA with the Convair 580. The data to be recorded includes:

Loran-C Indicated Position (711)
Loran-C Indicated Position (424)
Ground Reference Indicated Position
Real Time
Cross Track Deviation
Distance to Waypoint
From/To Flag Indicator
Loran-C Signal Indicator (Station Status, TD, S/N)

TERRESTRIAL APPLICATIONS OF LORAN-C FOR THE STATE OF NEW YORK

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TERRESTRIAL APPLICATIONS OF LORAN-C FOR THE STATE OF NEW YORK

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ABSTRACT. This paper describes the LORAN-C Terrestrial Applications Program presently being conducted by the U.S. Department of Transportation, Transportation Systems Center and the State of New York, Department of Motor Vehicles. The primary objective of the program is to determine and demonstrate the utility of LORAN-C for a number of land applications. These applications include using LORAN-C time-difference coordinates as the index for traffic records and highway inventories and for automatically locating and dispatching a selected fleet of police and emergency medical service vehicles. To achieve the stated objective, the formulated approach to the program includes: (1) the design of an experimental program to evaluate the operational feasibility of LORAN-C for the selected applications, (2) the design, assembly, and operation of LORAN-C based systems with capabilities for accomplishing location identification and automatic vehicle location, and (3) the conduct of a series of scientific and systematic experiments to assess the utility of LORAN-C for the aforementioned terrestrial applications. These experiments will be performed in a county (to be selected) in the State of New York.

INTRODUCTION

The value of radio techniques in providing navigation and position information to ships and aircraft has long been recognized. In recent years, there has been a growing awareness that similar techniques can be of use on land. This awareness is testified to by the variety of vehicle location, vehicle monitoring and vehicle identification systems that are being developed and demonstrated in numerous applications throughout the United States.

A somewhat different application that has recently been receiving increased attention is called location identification. It involves the determination of fixed positions on land, particularly on roadways in both urban and rural areas, for the purposes of accident location, highway inventories, and the fixing of landmarks. Location identification in some form is required of state and local governments by Federal Safety Standards as administered by

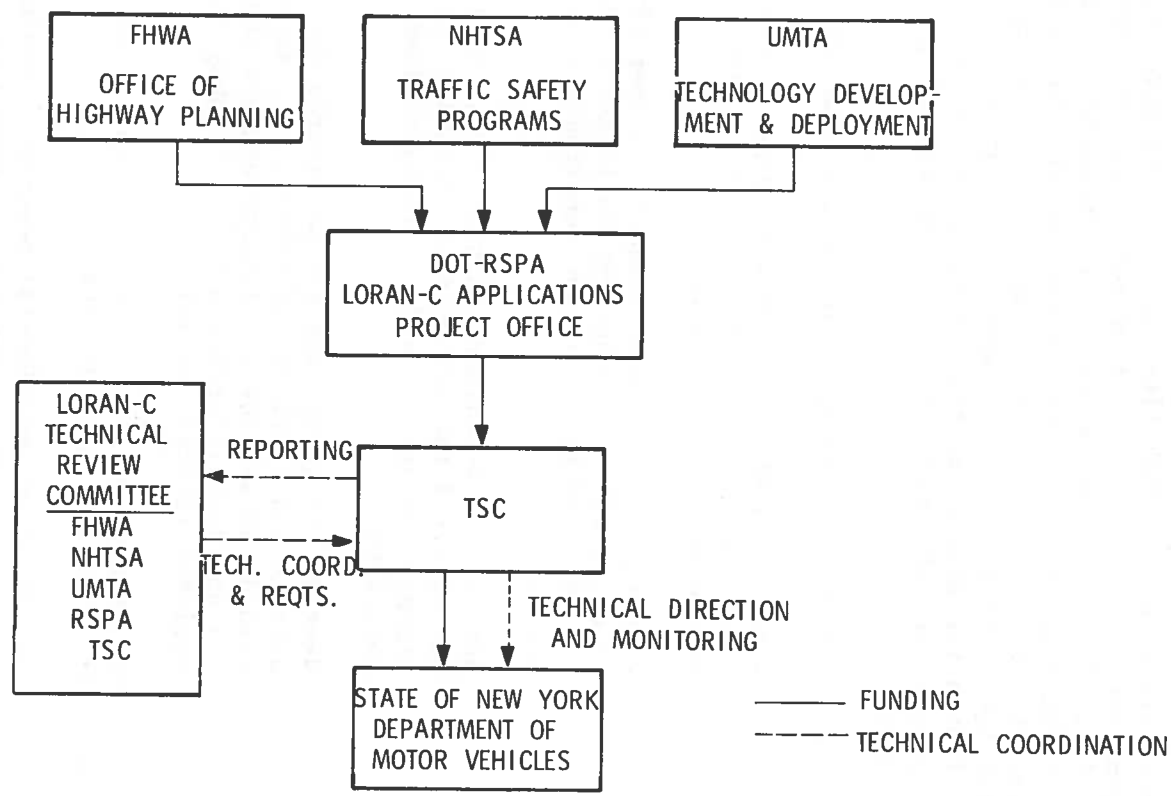

FIGURE 1. PROGRAM ORGANIZATIONAL INTERRELATIONSHIPS

The following sections discuss the two major areas of the program, namely the experimental effort and the systems required to carry out the experiments.

THE EXPERIMENTAL PROGRAM

Central to the program is the design and execution of a series of systematic and scientific experiments to evaluate the use of LORAN-C for location identification and automatic vehicle location. Three distinct but interrelated experiments have been identified. These are:

- traffic records and highway inventories in LORAN-C coordinates
- LORAN-C in the dispatch of police vehicles
- LORAN-C in the dispatch of emergency medical service (EMS) vehicles.

An important part of the experimental design effort is the selection of the experiment site. The experiments as identified above will be conducted in a county (to be selected) in the State of New York. To support New York in the selection, TSC is currently in the process of making measurements of LORAN-C coverage and signal to noise ratios in a number of counties. The TSC measurements are being coordinated with the Coast Guard since the LORAN-C chain providing coverage to New York will be the new Northeast Chain --- presently undergoing final testing prior to becoming operational in the very near future.

The following paragraphs discuss each of the three experiments.

Traffic Records and Highway Inventories Experiment

The objective of the experiment is to evaluate the utilization of LORAN-C as the index for traffic records and highway inventory location identification. As used in this paper, traffic records refer to accident and traffic citation data. A highway inventory is a cataloging of the physical features and elements pertaining to a given roadway.

Accurate, unambiguous location identification is an essential need in highway safety planning and management. Location identification is defined as the recording of the geographical extent of a highway characteristic or location of a particular site which has significance and is to be recorded for purposes of inventory, analysis, correlation, etc.

Highway inventory files now generally use a route number and accumulated mileage (called mile points) from a zero point for identification of segments of highway. A segment of highway usually becomes a record in the file and is determined by having the same characteristics throughout its length, i.e., the same width, surface type, shoulder width, number of lanes, etc. Where any of these characteristics change in value, a new segment begins. Thus, segments generally are identified in terms of mile points (usually in terms of hundredths of a mile). A problem arises whenever a construction change shortens or lengthens a route, since the mile points for that route must be adjusted, which often can be a cumbersome procedure.

DISPATCH OF POLICE VEHICLES EXPERIMENT

The objective of this experiment is to evaluate the use of LORAN-C in automatically locating and dispatching police vehicles in real-time over a broad operational area.

The capability to locate and monitor land vehicles in real time is recognized as a means to improve efficiency and service in fleet operations, particularly in fleets that are dispatched from a central headquarters, such as police vehicle fleets and emergency medical services. Police dispatch personnel have a need to know the location of all patrol cars at the time of an emergency to permit optimal dispatching of vehicle(s) to the emergency or crime scene. This can decrease the requirements for small area patrol zones. Tracking of police vehicle fleets also provides increased safety for the police officer as well as increasing the overall efficiency of the police department.

The hypotheses to be tested in this experiment will include:

- the utilization of LORAN-C coordinates for locating and dispatching police vehicles is operationally feasible and beneficial.

- the utilization of LORAN-C coordinates to locate and dispatch police vehicles reduces the response time.

- an increase in efficiency in the use of the police vehicle fleet due to availability of location information.

- the silent alarm installed on police vehicles is effective and provides increased safety for police officers.

DISPATCH OF EMS VEHICLES EXPERIMENT

The objective of this experiment is to evaluate the use of LORAN-C in automatically locating and dispatching EMS vehicles operating in a rural area.

Accidents related to motor vehicles constitutes the leading cause of death for all age groups under 75 years and 70 percent of those accidents occur in rural areas and in communities with populations under 2500. Studies of trauma deaths in Vermont, California and elsewhere indicate that between 23 and 35 percent of trauma deaths studied were either definitely or possibly survivable. A definitely survivable injury is defined as one which would have been clearly survivable if the victim had received early and basic emergency medical aid such as the control of bleeding, the clearance of an airway or the splinting of a fracture. A possibly survivable injury is one in which the injury or combination of injuries is more serious, but in which it is felt that the victim would have survived had the best care currently obtainable in many communities been provided. The response time of a person trained and capable of rendering basic stabilizing aid to a victim of an accident or medical emergency is critical in any location, but becomes particularly acute in rural areas. The

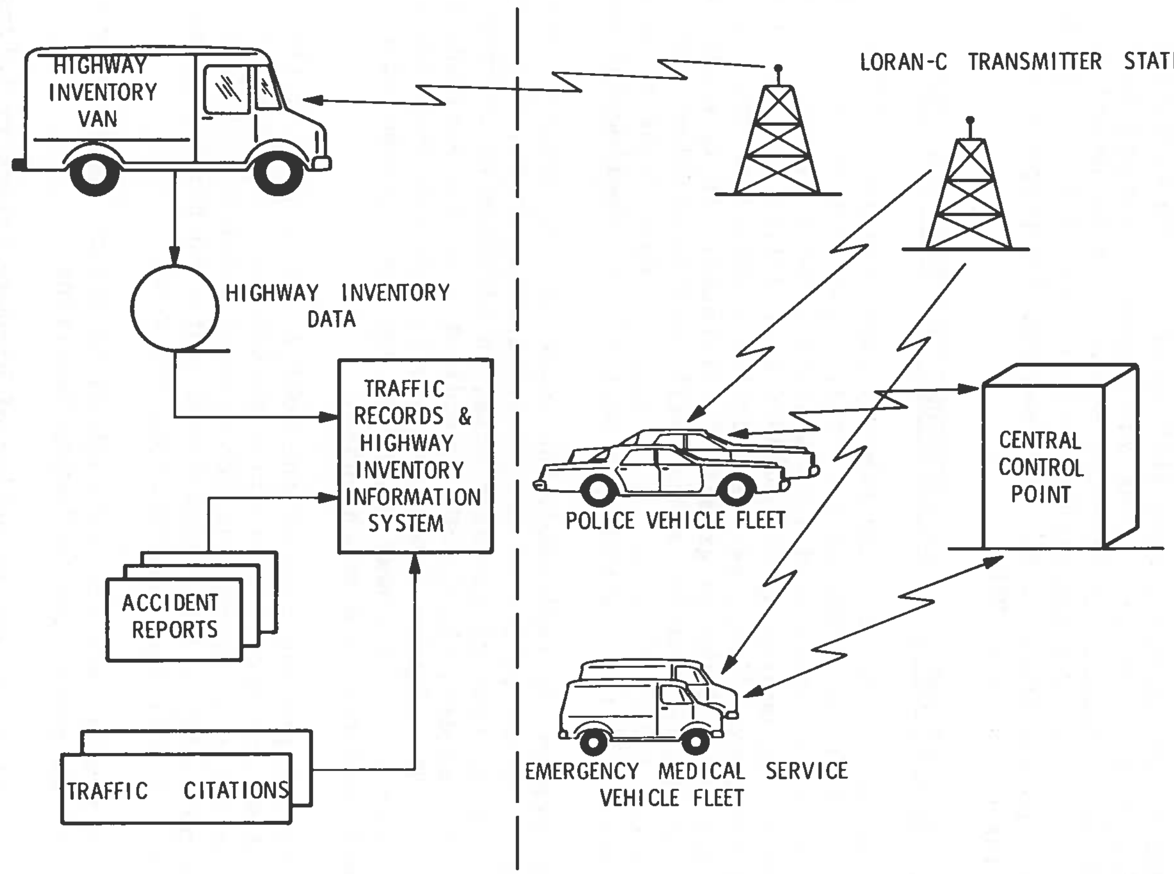

FIGURE 2. EXPERIMENTAL PROGRAM LORAN-C BASED SYSTEMS

- Tabulation of highway characteristics for a given road section specified by LORAN-C time-difference coordinates.
- Tabulation of characteristics and data for accidents occurring on a given road section specified by LORAN-C time-difference coordinates.
- Tabulation of characteristics and data for traffic citations issued on a given road section specified by LORAN-C time-difference coordinates.
- Correlation of accident-location sites to highway characteristics (in order to identify design and operating features with which high accident frequencies or severities are associated).
- Identification of high accident locations.
- Identification of locations where accidents are increasing sharply.
- Correlation of traffic citation sites to highway characteristics.
- Identification of locations of high traffic citation issuance.

VEHICLE LOCATION AND DISPATCH SYSTEM

The primary operational function of the LORAN-C based vehicle location and dispatch system is to monitor the selected police and emergency medical service vehicles dispersed within the experimental site and to determine, at any time, at a central control point, their location and status. The vehicle fleet to be instrumented will include 12 police vehicles, 12 EMS vehicles, and 1 EMS helicopter. The vehicle location and status information will be presented to the dispatcher located at the central control point. This information is then used to efficiently assign and deploy the vehicle fleets.

For the police vehicles, the system will also include emergency alarms that will enable the vehicle operators to signal the dispatcher for emergency assistance.

The LORAN-C vehicle location and dispatch system will be designed, developed/assembled, and deployed to accomplish the following functions:

- Determination at any time, at the central control point, the location of the instrumented police and emergency medical service vehicles.
- Determine at any time, at the central control point, the status of the instrumented police and emergency medical service vehicles as to whether:

FAA OFFSHORE HELICOPTER NAVIGATION

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OFFSHORE HELICOPTER NAVIGATION

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ABSTRACT. Extensive offshore helicopter operations are now providing air logistic support for oil and gas exploration. Their activity covers all the coastal areas of the United States and the numbers of operations are expected to grow dramatically. They have particular requirements for air navigation, the most significant of which is high accuracy far beyond the line of sight from land based stations. The FAA's responsibility for safety of civil aviation includes approval of offshore helicopter operators' navigation systems and procedures. The FAA is currently evaluating systems with the capability to meet the requirements and is preparing to establish criteria for approving suitable systems for offshore helicopter navigation.

I. INTRODUCTION.

This paper describes a significant new segment of aviation requiring new solutions for air navigation. It is the operation of helicopters serving industry in the exploration and production of oil and gas in the offshore areas.

While this paper discusses a navigation problem associated with the growing offshore helicopter activity, that problem is only one part of a bigger one. The entire helicopter industry is growing faster than any other segment of civil aviation today. In 1976, the industry recorded an 18% growth. The number of civil helicopters in the U. S. is expected to double by the mid-1980's with most of these new aircraft capable of operating IFR. The magnitude of this growth demands a new look at all the services provided for helicopters to assure that their unique capabilities can be used efficiently and not handicapped by things such as traffic control procedures, communication systems or navigation systems. The FAA has established a Helicopter Operations Development Program for that specific purpose.

The present growth of helicopter operations is the result of two factors: one is that new technology has made significant improvements in helicopters in recent years, and the second is the great search for new energy resources. This search has extended to the continental shelf in the Gulf of Mexico, the Atlantic Coast from Jacksonville to Cape Cod, the Pacific Coast, and off Alaska. All these activities depend heavily on helicopters for personnel movement and light logistic support.

THE OFFSHORE NAVIGATION REQUIREMENT FOR HELICOPTERS

It is worth mentioning some basic reasons for using a good navigation system for these operations. It is needed not simply to find the destination and avoid getting lost, but for efficiency in conducting the flight. And when some need arises during the flight to change the destination, the pilot must be able to quickly and accurately determine how to get to his alternate. Helicopters are generally limited in their weight-carrying capacity and fuel reserve is critical. They cannot afford to waste time in the air.

Even on VFR flights, it is necessary for some flight-following service to know accurately where each helicopter is offshore in order to carry out a rescue service when that is necessary; and that information must come from aircraft position reports because these operations are carried out beyond the coverage of independent radar surveillance.

For the same reason, it is necessary to use position reports for traffic control. The spacing between aircraft and the capacity of the controlled airspace is thus dependent upon the reliability and accuracy of the navigation system.

The navigation system must have a high level of safety (or integrity) and reliability. When it is working, it must not give false or ambiguous information; and of course it must work when it is needed. (A frequent criticism of one of the older navigation systems used by helicopters has been that it works fine except when it is really needed.) To fully meet the reliability requirement with any single navigation system, it may be necessary to install dual equipment in the aircraft, and the radio navigation systems must provide redundant signals over the offshore route structure to preclude loss of navigation when transmitters fail.

The coverage required of a navigation system for these operations creates the greatest problem. The helicopters fly well beyond the line of sight for VHF systems located on land. Some of the destinations are more than 200 miles off shore, and the pilots may need to cruise enroute as low as 500 feet above sea level to stay below icing conditions or for other practical reasons.

In the terminal area accurate guidance is needed down to at least 200 feet and preferably lower. In an offshore area where there are a large number of oil rigs, the traffic density can be high, and several prescribed tracks will be needed. In the most crowded situation, it may be argued that the same accuracy would be needed for area navigation offshore as is needed on shore: $\pm$ 2 mile widths for airways; but generally it may be expected that $\pm$ 4 miles could be adequate.

The rescue requirement demands the best accuracy achievable. (Imagine the accuracy needed to find a single person floating at sea in a Mae West at night or in fog.)

Guidance in the terminal area is required to permit Category I approaches - with a 200-foot ceiling and one-half mile visibility. Greater precision to achieve lower weather minima is desired for the future if it can be provided economically.

VOR, DME, and TACAN systems are limited to the VHF line-of-sight and would require a large number of offshore installations to provide the necessary coverage beyond 200 miles. At a 500-foot altitude, the useable range for these systems is between 33 and 40 NM depending on the height of the transmitter. At higher altitudes, the 4 NM accuracy requirement is exceeded beyond about 50 NM.

NDB's are generally limited in range and have less accuracy than VOR. Extensive coverage with a large number of low-frequency NDB's would pose a frequency management problem, and they have a long history of susceptibility to radio noise from thunderstorms.

Inertial systems available today are too expensive for serious consideration. Perhaps as this technology continues to reduce the cost of inertial navigation systems, their use may some day become practical in small helicopters - but not now.

The accuracy of Doppler navigators degrades at a nominal rate of 1/2 NM per hour along track and, across track, at the rate of 2% of the distance travelled. At 300 NM from shore the total Doppler error would exceed 6.0 NM.

Omega/VLF systems will meet the requirements for accuracy and coverage for enroute operations but experience has shown that the signals can be lost for several minutes at a time in heavy precipitation and there is a possibility of several miles' error when the system is initialized after signals are acquired again. For this reason, some backup means is needed to re-initialize an Omega receiver after loss of signal. Omega does not meet the accuracy required for non-precision approach guidance at the destination.

LORAN-C has the potential for meeting the requirements for enroute navigation and may have the accuracy suitable for non-precision approaches, but we need to know more about its performance and potential faults in low altitude helicopter operations before saying much more about it.

GPS is an interesting possibility for the future, but of course is not available today.

Airborne radar is already proving suitable as a backup to other systems for enroute navigation to recognizable landmarks and oil rigs, but it is not suitable as a primary means for area navigation. Its principal utility for helicopters lies in its utility for non-precision approaches.

The Microwave Landing System has great potential for terminal guidance since it was developed specifically for that purpose, but more work is needed to determine how to use it on an offshore platform that pitches, rolls, and heaves, however, slight that might be.

Visual aids are included in the list of possible navigation aids as a reminder that they do have utility under visual conditions - particularly at night. And approach guidance can be provided with lights, as it is on Navy ships, to enhance safety in the final stages of landing.

These efforts will define the capabilities and limitations of the systems. For safety purposes, they also seek to identify possible system faults, and define suitable means for overcoming those faults. The solutions may involve the development of monitors to detect and report faults, development of alternate traffic control procedures or flight procedures to be invoked when a failure occurs, or redundancy in ground or airborne equipment to assure continued, normal operation.

SUMMARY:

In summary, offshore operations of helicopters are dramatically increasing in numbers and the new growth is occurring in areas requiring navigation during instrument flight. The navigation requirements for these operations cannot be met by standard systems and for air navigation over land in the United States. They require reliable and accurate systems capable of long range coverage at low altitude and in unique environmental conditions.

Omega/VLF and airborne radar systems are currently being used for offshore helicopter operations, and GPS has potential for the future; but LORAN-C and airborne radar currently appear to be the most attractive systems for the near future.

The FAA is now evaluating all the available new systems to prepare criteria for approving their use for offshore helicopter navigation.

USCG HELICOPTER FLIGHT TEST

David Firestone
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U.S.C.G. HELICOPTER FLIGHT TESTS

David D. Firestone

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ABSTRACT The Coast Guard is currently in the first production and operational flight test stage in the development of the AN/ARN-133 Airborne Loran C Navigator. The navigator is being tested in both HH3 and HH52 search and rescue helicopters to evaluate its effectiveness in the execution of Coast Guard missions as well as its performance in the National Airspace System (NAS). Data from these tests, when merged with that of the prototype model test, will provide a comprehensive data base supporting FAA approval of the system for use in the NAS by U.S. Coast Guard helicopters. Results to date indicate that the various test data fall within the limits established by FAA Advisory Circular AC90-45A. Plans for the remaining flight test program include a cooperative effort with the FAA in support of offshore operations and the implementation of additional Northeast Corridor routes.

INTRODUCTION.

Since 1975 the Coast Guard has been engaged in a program to develop an airborne Loran C navigator system for use on our HH3 and HH52 search and rescue helicopters. Primarily targeted for the single turbine HH52 the AN/ARN-133 Airborne Loran C Navigator is designed to provide precise navigational capabilities in the offshore environment not normally provided with other RNAV coverage such as VOR/DME. Since the Department of Transportation National Navigation Plan (reference 1) designates Loran C as the government provided radio navigation system for the coastal confluence zone, a reliable, accurate system of navigation will be available in the area of greatest interest to the Coast Guard. As Loran C is more widely adopted by the maritime community, the importance of search and rescue efforts being tied to a single coordinate system for navigation will increase. Coordination between surface and airborne SAR units will also be greatly aided by a common reference system.

Ref. 1. Anonymous, Department of Transportation National Plan for Navigation. DOT-TST-78-4 November 1977.

As an aid in interfacing with ATC and in performing SAR missions, the navigator has the ability to generate waypoints based on range and bearing (rho-theta) information from a known position.

Of particular importance to the Coast Guard is the ability to fly SAR search patterns automatically using the navigator. After the pilot enters the basic parameters of the search, the computer can guide him through either a creeping line or sector search. These routines also permit the pilot to depart from the search to investigate a possible sighting, then return to his point of departure to resume the search, thus maintaining the maximum probability of detection.

One additional feature which has an important impact on the flight test program should be described. The navigator has the capability of inputting the known position of the aircraft and generating correction factors which it applies to its calculated position and effectively shifts the grid to the new "updated position". All subsequent position calculations include these corrections until such time as the "update" is removed by the operator. The non-volatile memory makes this update feature important since it is not necessary to re-update before each flight, as is the case, for example, with an inertial system.

FLIGHT TEST PROGRAM

Proceeding on to the flight test program, it is necessary to realize that two test sequences are involved. The first was a test of the prototype system conducted in late 1976. The second, which is currently underway, involves the verification of the production model with the prototype data. Both test plans were developed under contract by Champlain Technology Industries Division of Systems Control Inc. (VT). In addition to preparing the test plans, CTI personnel monitor the flight procedures and reduce the resultant data, which they analyze and formulate into their final report. The reader is directed to reference 3 for the details of the prototype test results.

Prototype Tests

The goals of the prototype test sequence fell into four general areas:

First was to determine the characteristics of the navigator in the performance of realistic Coast Guard search and rescue missions.

Ref.3. Hughes, M. and Adams, R. J., "An Operational Test Evaluation of a Loran-C Navigator", Department of Transportation, U.S. Coast Guard Report CG-D-9-77, NTIS ADA 039 498. March 1977.

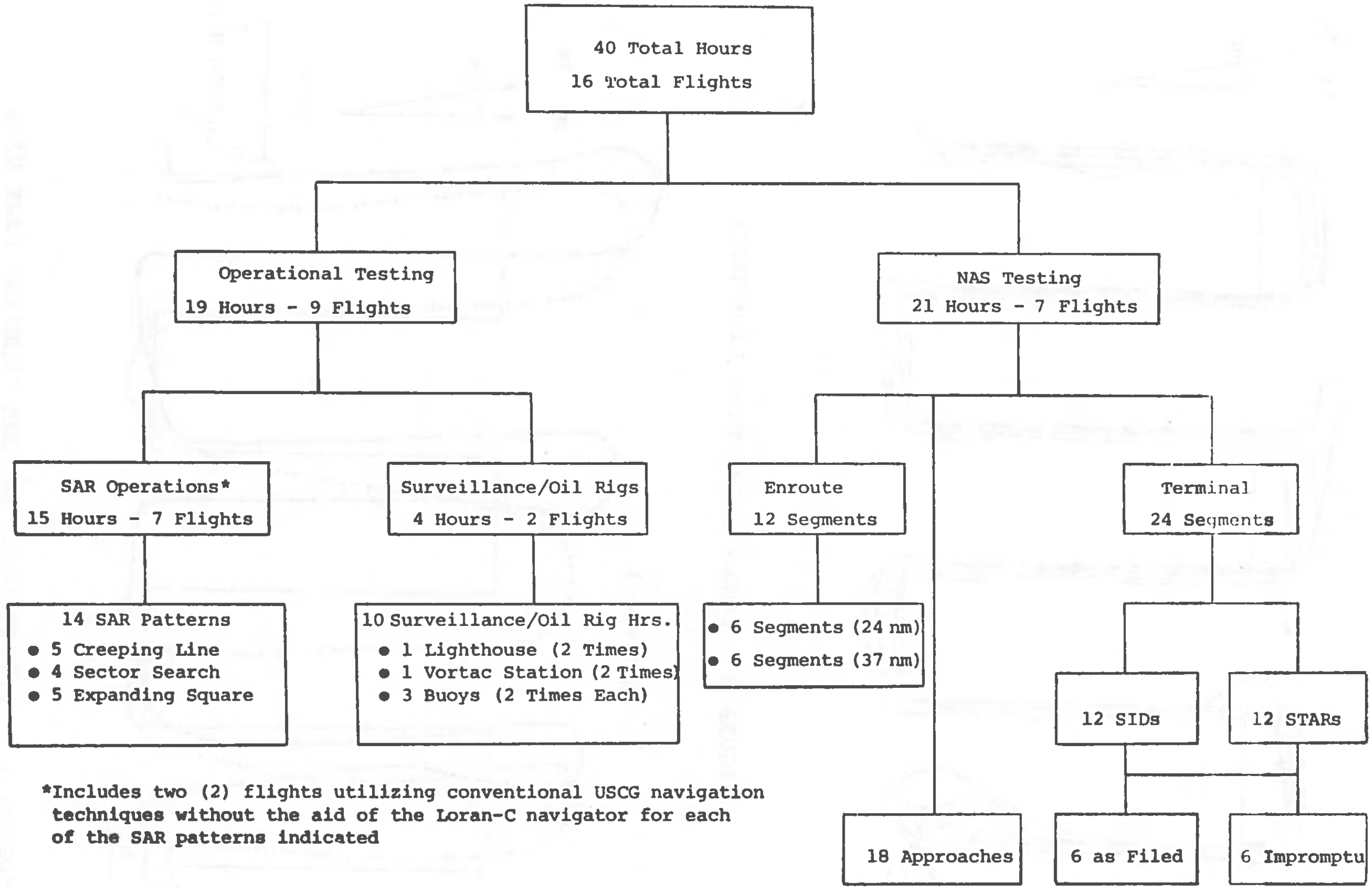

FIGURE 1 PROTOTYPE FLIGHT TEST MATRIX

with VOR/DME using standard Coast Guard procedures in Figure 3. Figures 4 through 6 are the plots of the enroute, terminal and non-precision approach segments of the NAS tests. Note that the dashed lines represent the limits specified by AC90-45A. A statistical summary of the NAS data is presented in Table 1. Note that with the exception of only one datum the results fell well within the limits of AC90-45A.

Production Model Testing.

With the prototype test as a basis, several modifications were made to improve the man-machine interface and the operating procedures of the navigator. This involved modifying the front panel, adding the programmed search routines and improving many of the software routines. The resultant production model is shown in Figure 7. Flight tests of the production model were designed to verify the data taken in the prototype testing and to demonstrate some additional operational features of the system. The specific test objectives are:

1. To verify the navigation accuracy and technical performance of the production version of the AN/ARN-133.

2. To demonstrate operation of the Loran C Navigator in the Northeast Corridor ATC environment. The number of enroute, terminal and approach segments flown shall be sufficient to demonstrate compliance with charted helicopter routes and control procedures, and show compatibility with the other National Airspace navigation systems.

3. To evaluate the Loran C Navigator as an approach aid to the flight decks of ships, offshore oil rigs and unaided helipads. In particular, to evaluate the production version Loran C Navigator telemetry functions (two-way data link).

4. To supplement the previously acquired Loran C Navigator IFR certification data, for AC90-45A compliance, for operations in both HH3 and HH52 helicopters.

5. To demonstrate operation of the Loran C Navigator during long range overwater missions.

Figure 8 is the flight test matrix for the production model flight tests.

NEC Test: The Northeast Corridor Test involved navigating the prescribed experimental helicopter routes between Boston and Washington, D.C. via New York and Philadelphia. With the HH3,

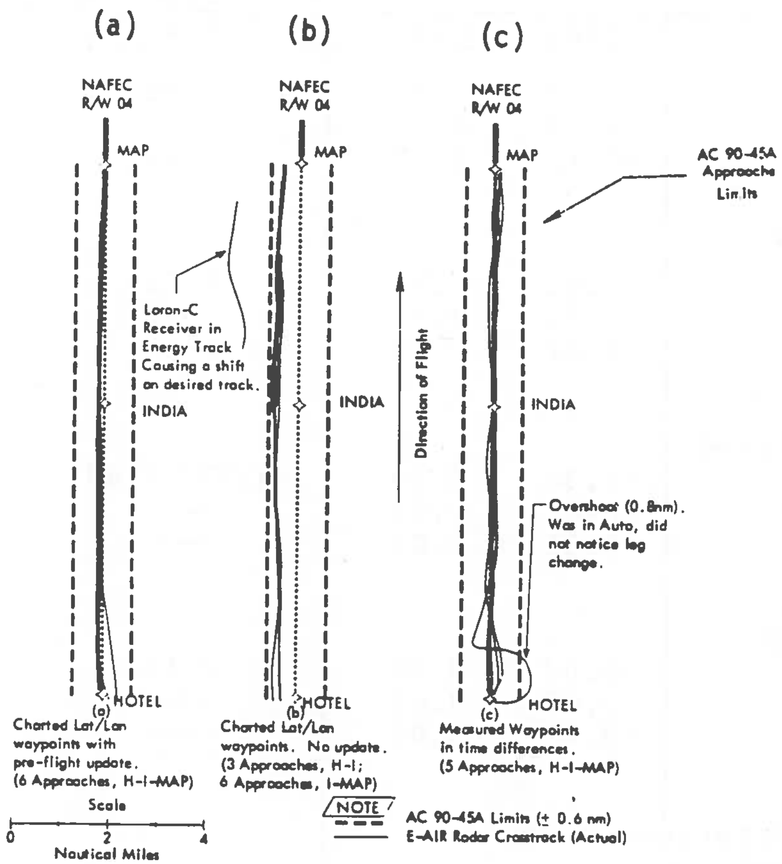

FIGURE 6 NON-PRECISION APPROACHES

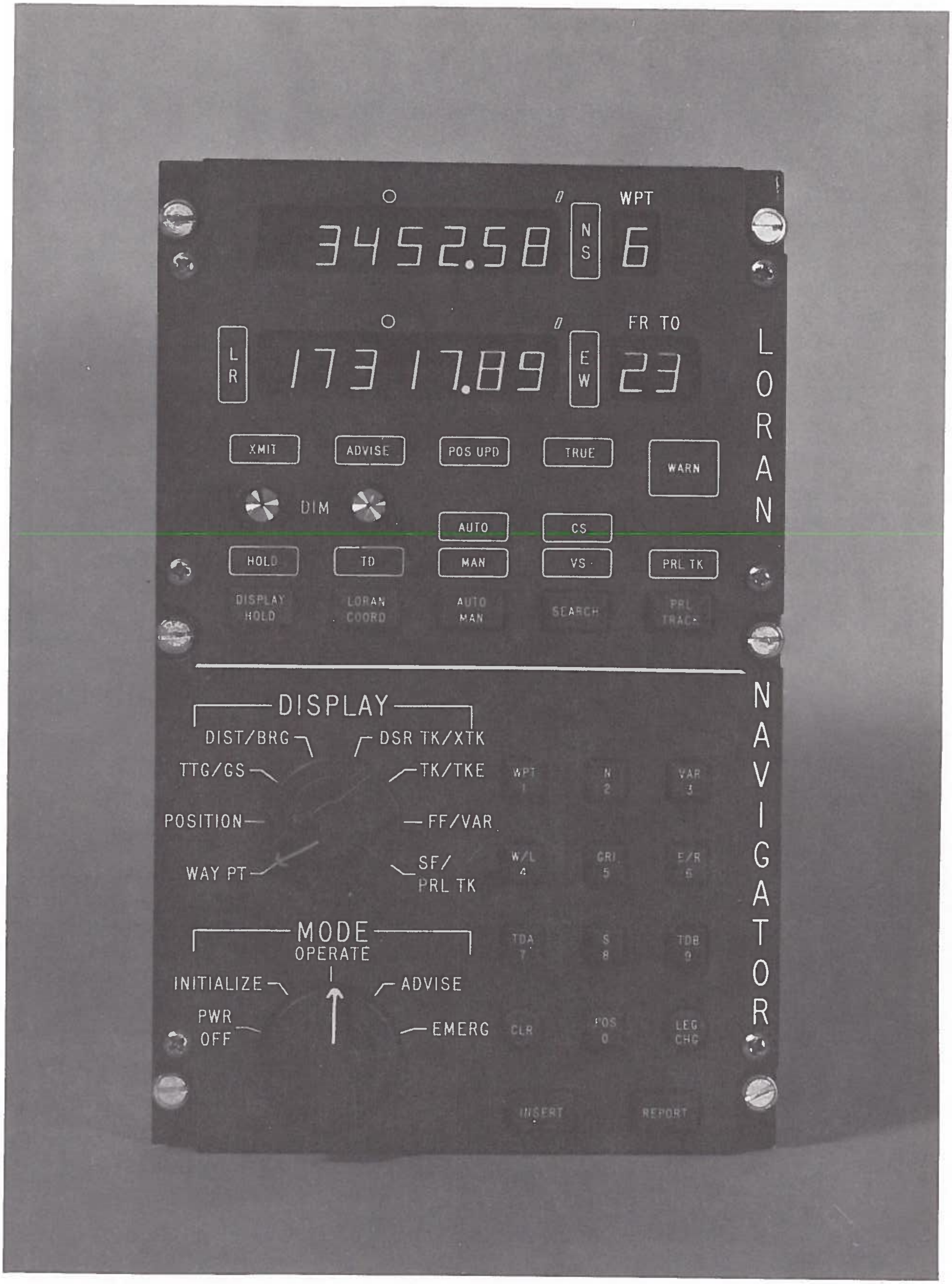

FIGURE 7 PRODUCTION MODEL AN/ARN-133 AIRBORNE LORAN C NAVIGATOR

this entailed a planned sequence of five flights and 16 hours of flight time. Extensive coordination was required in obtaining ARTS III radar coverage over the entire route for ground reference data. An HH3 helicopter was selected for its long range capability. Along track and cross track data, as well as position data was recorded onboard as a measure of Flight Technical Error. Although ARTS III data was not expected to be as accurate as NAFEC's EAIR, it is considered sufficient to demonstrate the capability to navigate the corridor well with in published limits.

Deep Probe Test: To demonstrate the long range capabilites within the Coastal Confluent Zone, a deep probe test was planned to a distance of 200 nm east of Atlantic City, N.J. Radar coverage was to be provided by NAFEC's EAIR radar to a distance of approximately 120 nm. The HH3 was to climb to approximately 2700 m (9000 ft) to maintain radar coverage then drop to approximately 300 m beyond range. The track was approximately aligned along the recently established helicopter routes to offshore oil rigs east of Atlantic City.

NAS Tests: In a manner similar to the prototype tests, NAS enroute and terminal area segments, as well as non-precision approaches were planned utilizing the facilities at NAFEC. Both helicopters were to fly a total of five flights encompassing eight hours of flight time. Enroutes totalled six segments and 185 nm. Terminal area flights came to 30 segments and 347 nm, while 12 approaches were flown totalling 66 nm. The HH52 flights have been completed and data is being reduced.

SAR Tests: An HH52 from USCG Air Station, Cape May, N.J. flew two SAR test flights totalling four hours. During these flights, those features particularly applicable to the SAR mission were tested. Using the two preprogrammed routines, the aircraft navigated creeping line and sector search patterns. While executing the search patterns, the added feature of depart-search-and-return was evaluated. This feature enables the pilot to leave the search pattern, investigate a point of interest and return to the point of departure in the search pattern. After completing the search sequence the pilot flew to a rho-theta waypoint which was created with reference to a fixed point in space, thus demonstrating both SAR rendezvous and ATC capabilities. The rho-theta portion was followed by a parallel track leg in which the pilot flew a leg 3 nm right or left of a prescribed course before executing a leg change and returning to base.

Offshore Oil Rig Tests: Of increasing importance is the ability to navigate to and pinpoint a specific oil rig either from among a group or in an isolated position at an appreciable distance offshore. To demonstrate this capability several rigs were selected in the Gulf of Mexico approximately 70 nm south of Mobile, Alabama. One rig was isolated, another was in a small

TABLE 2 SAMPLE NAS STATISTICS FOR PRODUCTION MODEL

SEGMENTS	TSCT		FTE		CTE	
	M	± 2σ	M	± 2σ	M	± 2σ
ENROUTE	.1768	.0746	.0210	.0776	.1558	.0566
TERMINAL	-.0403	.1224	.0155	.1412	-.0558	.0502
	-.1084	.1720	.0104	.1574	-.1188	.0724
	.0979	.1046	.0015	.1040	.0964	.0328
	.0708	.1272	.0154	.1278	.0554	.0888
APPROACH	.0797	.1338	.0830	.2882	-.0033	.0532
	.0120	.0994	.0178	.0814	-.0058	.0438
	.0567	.2508	.0913	.3052	-.0346	.0704
	-.0208	.1706	.0144	.2014	-.0352	.0666

TSCT--Total System Cross Track Error
FTE--Flight Technical Error
CTE--Airborne Equipment Error

PHASE II PRODUCTION MODEL TESTING

As the tests progressed, it became apparent that additional flight time would be necessary to reach the data goal of the program. In preparing for this second phase of production model testing, an opportunity arose for cooperation with the FAA in some helicopter testing in the Northeast Corridor, which would be mutually beneficial to both agencies' programs. Approximately forty-one hours will be required to complete Coast Guard requirements. This time is allotted to both HH3 and HH52 aircraft in the areas of NEC, NAS approaches and offshore operations. A total of thirty additional hours of testing are being requested by the FAA involving the investigation of spurs off the NEC, addditional approaches at NAFEC and creeping line searches along the coast line to investigate the land/sea interface effect on signal propagation. Table 3 is the allotment of flight hours to each test in the proposed Phase II testing.

SESSION IV
NAVIGATION SYSTEM TECHNOLOGY

Chairman
Joseph Gutwein, Chief
Communications Branch, TSC

LORAN-C DEMONSTRATION LABORATORY

Richard Smith
Office of State
Program Assistance, NHTSA

LORAN-C DEMONSTRATION LABORATORY

Richard H. Smith

Department of Transportation
National Highway Traffic Safety Administration
Traffic Safety Programs
Office of State Program Assistance
Information and Records Systems Division

The basic objective of this presentation is to discuss the system components and their individual functional applications of the joint National Highway Traffic Safety Administration/Federal Highway Administration project, and some of the operational problems encountered.

Good morning ladies and gentlemen. Since this presentation is the first on today's agenda - I'm sure that it's really too early to start wading right into something really heavy - so I'll make every effort to keep it light and flexible, and attempt to avoid dwelling on the detailed technical aspects. Another basic reason for circumventing the logic and circuitry of the various components is, in view of my rather limited electronic background, I can only relate upon the basic functions of the individual units, the overall operational aspects, our primary goals and objectives, and the progress to date.

In recognition of the great potential use of LORAN-C for highway traffic safety applications, a joint National Highway Traffic Safety Administration/Federal Highway Administration LORAN-C Demonstration Laboratory (LDL) project was initiated in January 1977. The primary objectives of this jointly funded project were to evaluate and demonstrate under controlled test conditions the capabilities of utilizing LORAN techniques for the following basic functional applications:

- Precise position location and identification
- Vehicle dispatch and tracking
- Map development
- LORAN accuracy and repeatability

A key to convincing potential user agencies (federal, state, local) of the values of LORAN is to provide a means of demonstrating the capability of LORAN in a setting that is real and relevant to the potential agency. In conjunction applications. It is primarily used in the LDL for initial offline calbration of local area maps shown on the display terminal through computation of LORAN coordinate conversion parameters (regression analysis).

Digital Tape Recorder (Tektronix 4924)

Provides storage of the microcomputer operational programs and map data.

Graphics Display Terminal (Tektronix 4010-1)

Provides the keyboard control for the microprocessor, and the input of map data or programs into the microcomputer. The display screen is used for visual functions of the system - maps, tracking vehicles, location of time difference readings displayed on the map or vice versa position location of LORAN time difference coordinates. The Hard Copy Unit & Graphics Tablet are interfaced directly into the Graphic Display Terminal.

Hard Copy Unit (Tektronix 4631)

Will provide an image on paper for permanent retention of any display on the screen.

Graphics Tablet (Tektronix 4631)

This unit provides an easy method to trace maps for inclusion in the system inventory for display on the Cathode Ray Tube (CRT). The other method for producing maps is through the utilization of light and dark vectors input through the keyboard of the Graphics Display Unit (an acetate tracing of the desired area must first be traced then taped on the CRT screen as a guide for placing the light vectors in the map program.)

RFL Demodulator

Translates the frequency shift keyed signal transmitted over the transceiver or stored on the analog tape to a digital signal acceptable to the microcomputer.

Just don't ask me exactly what all that jargon really means. It's a bit out of my field.

GE Transceiver

Land mobile transceiver (41.39 MHz) provides unidirectional data transmission from the test vehicle to the base station (Central Control) and bidirectional voice communications between the base station and test vehicle.

Sony Stero Tape Recorder

Can be used either in the base station or test vehicle to record the LORAN and State Information. Recordings can be replayed through the demodulator at the base station for system demonstration.

In map production the projection and calibration of local area maps (Rochester, New York and San Diego, California) we need more guidance and experience in the establishment of both geographic and LORAN coordinate calibration computations. Especially in regards to computation of large scale maps where there is a very small variance in the LORAN time difference readings.

SUMMARY

So far we feel that we have had a successful demonstration laboratory within our basic objectives of both demonstrating and evaluating LORAN capabilities in highway safety applications. We are gaining a wealth of experiences that we'll be able to relate to other interested federal, state and local agencies, perhaps can alleviate reoccurances of problems we have encountered.

Thank you.

LORAN-C ON THE ST. MARY'S RIVER

Lt. David Olsen
Office of Research and Development, USCG

LORAN-C ON THE ST. MARYS RIVER: AN EXPERIMENT IN PRECISION NAVIGATION

Lt. David L. Olsen

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Washington, DC 20590

ABSTRACT The United States Coast Guard is examining the use of a Loran-C mini-chain and automatic shipboard user equipment as a navigational aid for commercial vessels transiting the St. Marys River.

The St. Marys River, located in northern Michigan near the city of Sault Ste. Marie, serves as the only water shipping route connecting Lake Superior with the rest of the Great Lakes and the St. Lawrence Seaway. The 65-mile river, which is traversed by iron ore carriers up to 1000 feet long and 105 feet wide, has channels as narrow as 300 feet. An experimental Loran-C mini-chain was established by the Coast Guard in 1976 to investigate the feasibility of providing an all-weather, year-round navigation capability. Shipboard user equipment has been developed to process the mini-chain's signals and provide continuous position fixes on the river. Initial tests were performed on U.S. Coast Guard vessels to determine the feasibility of using Loran-C as a navigation aid on the St. Marys River. Further tests were performed in the summer of 1977 and the winter of 1978 on the Arthur M. Anderson, a 767-foot Great Lakes iron ore carrier. Accuracy tests were performed in the summer of 1978.

The ore carrier installation has shown the ability of the mini-chain and user equipment to provide useful, timely guidance information in restricted waters and in limited visibility conditions. Tests have shown the user equipment's off-track accuracy to be within 25 to 40 feet, depending on velocity. However, the temporal stability of the Loran-C time difference grid must be verified.

INTRODUCTION

The St. Marys River (Figure 1), which lies between Canada and the United States, separates Ontario from Michigan's upper peninsula. This 65-mile waterway connects Whitefish Bay in Lake Superior to DeTour Passage in Lake Huron and serves as the only water shipping route connecting Lake Superior with the rest of the Great Lakes and the St. Lawrence Seaway. The chains. Geometry of the mini-chain can be optimized to produce near-ideal grid crossing angles. Good signal strength from all stations is more easily attained. The short baselines eliminate problems with skywave interference and minimize variations caused by propagation effects. It is easier to monitor and control the mini-chain from a single point near the middle of the service area.

The need to test the full capability of the mini-chain approach and the requirement for precise, all-weather, year-round navigation on the St. Marys River led to the decision to install an experimental Loran-C mini-chain for evaluation on that waterway. This installation offers the opportunity to test the ability of Loran-C to satisfy the particular navigational requirements of the St. Marys River, and an opportunity to judge its potential for application to other restricted waterways. In conjunction with the mini-chain, the Coast Guard has contracted the development of shipboard user equipment to provide navigation information to a vessel's conning officer.

This paper describes the Loran-C mini-chain, the shipboard user equipment, and the tests performed on this combined system aboard Coast Guard vessels and a commercial ore ship.

THE LORAN-C MINI-CHAIN

The St. Marys River mini-chain consists of four unmanned transmitting stations (one master and three secondaries) plus one monitor station as shown in Figure 2. The Master and Z-secondary stations are located in the Canadian

FIGURE 2 MINI-CHAIN CONFIGURATION

track through the river. This equipment, through automated processing of received Loran-C signals, gives a continual indication of off-track distance (lateral displacement from the intended track), time and distance to the next turn, along-track speed and cross-track speed. A graphics display, illustrated in Figure 5, presents a computer-generated geographic image of the St. Marys River including an outline of the channel edges, centerlines, buoys and lights. This synthetic chart is superimposed by a scaled representation of the user's vessel showing position and attitude in the channel. A heading vector projects a user-selected time or distance ahead of the ship. The user can select either a "North-Up" or "Track-Up" orientation and can change scale to show from one-half to ten miles of channel on a ten-inch square viewing area of the CRT. The upper right of the screen displays the off-track distance (OFF, feet right or left of channel centerline), gyrocompass heading (HED, degrees true), speed over ground (SPD, miles per hour), time to the next turn (hours, minutes, seconds), and distance to the next turn (statute miles). A CRT on the operator's console repeats this information and additionally displays the date and time of day, loran-derived latitude and longitude, loran-derived course made good, and the receiver tracking status for each station.

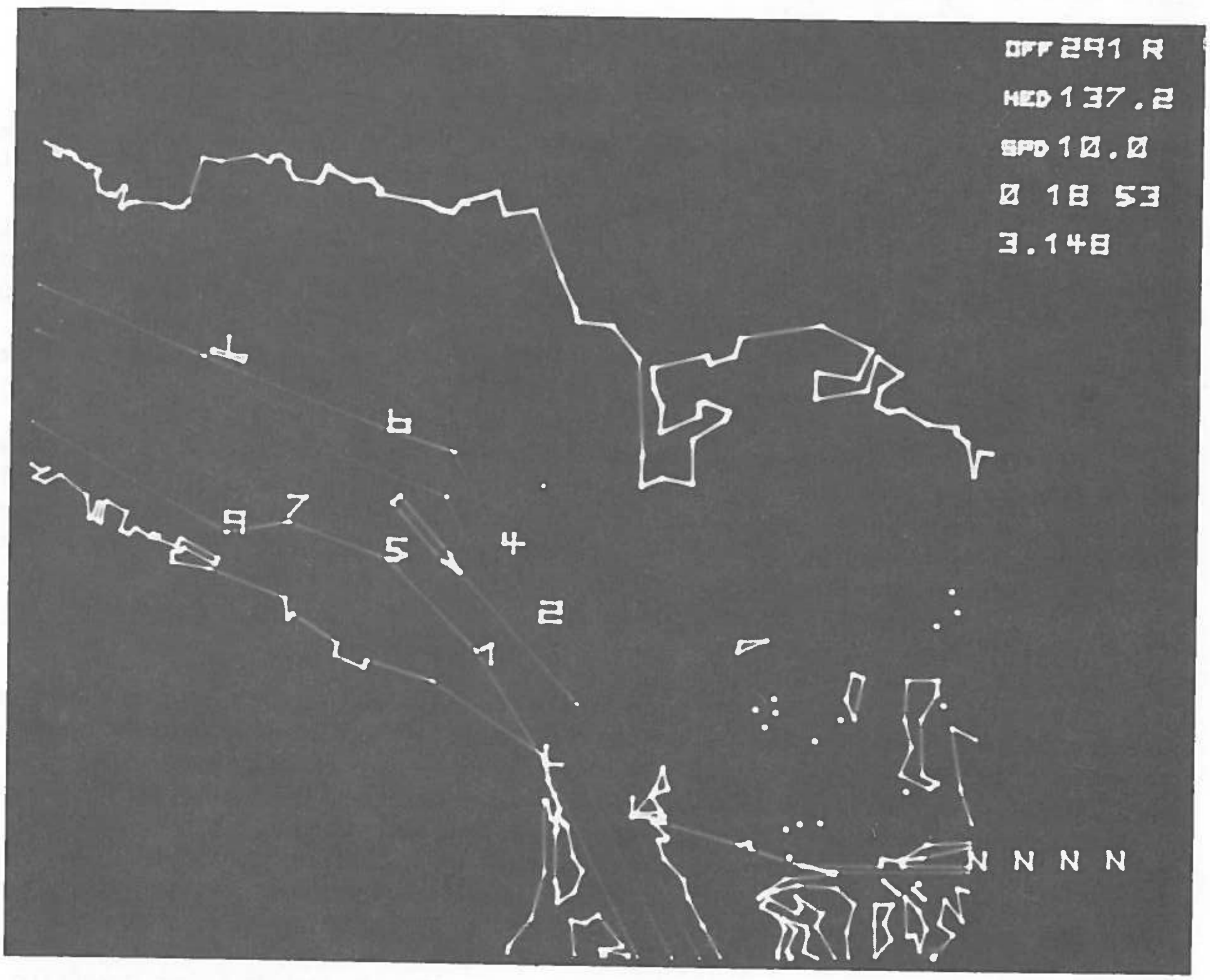

FIGURE 5 USER EQUIPMENT GRAPHICS CRT DISPLAY

FIGURE 6 THE STEAMER ARTHUR M. ANDERSON

the river, but the errors were too large to consider using the equipment for guiding the ship. After the waypoint adjustment the equipment's capability became more evident. The picture and data on the CRT agreed well with the ship's observed position. The highlight of the installation occurred when the Anderson was navigated upbound through roughly two-thirds of the river using the equipment for guidance. Throughout this exercise the Captain looked only at the CRT display, but he had the third mate on watch to verify whether the ship was actually safe and to warn of any approaching traffic.

Buoy Survey

Until the Anderson installation, the primary concern had been to insure an accurate indication of off-track distance plus an accurate CRT display of the ship with respect to the channel centerline. Hence calibration efforts had dealt solely with the center of the channel. The buoys and channel edges were not calibrated; their positions were picked from nautical charts of the river (1:40,000 scale). It was subsequently noticed that many buoys showed poorly on the CRT screen, with some errors as large as the 700-foot length of the Anderson. These errors became more evident after the waypoints had been refined and the equipment gained use as a navigational aid. During the Anderson tests several turns were noted where the ship might have been in danger of grounding had the Captain relied solely on the buoy positions displayed on the CRT. Buoys near channel intersections are especially important as they help determine when to put the ship's rudder over to start a upper river are quite wide and the ship encountered none of the river's more difficult turns. Nevertheless, the situation highlighted the potential utility of the system and demonstrated that a ship captain experienced with conventional navigation aids could quickly adapt to the informational format presented by the user equipment.

Accuracy Tests

The initial user equipment accuracy tests were conducted in September 1976, shortly after the equipment was first delivered to the Coast Guard. Several aspects of equipment operation have been changed since these first tests. Most significant are improvements to the gyrocompass implementation and the Kalman filter algorithm. Due to a malfunctioning gyrocompass interface, heading information was not available to the system during the initial tests on the Cutter Naugatuck. The interface problem has since been resolved and the navigational software has been improved to include rotational aiding in which any change in heading rotates the computed course vector by a like amount. This rotation is accomplished independent of the Kalman filter algorithm, and is especially helpful if the Kalman processing of heading is disabled due to expected crabbing or undetermined gyrocompass errors. As originally designed, the Kalman filter algorithm processed one set of three hyperbolic time differences every five seconds. The improved implementation processes the TDs as fast as three times every second. This higher rate takes better advantage of the information available from the mini-chain, and is especially helpful in a turning maneuver.

To determine the navigational accuracy of the improved system, the dynamic accuracy testing was repeated. In June 1978 the equipment was installed aboard the 38-foot patrol boat "J.P. IX" (Figure 7) which was leased from a firm in Sault Ste. Marie. A Motorola "Mini-Ranger III" microwave positioning system, consisting of a shipboard interrogator and two shoreside responders, provided the reference for these tests. A digital magnetic compass system was installed to provide heading information, as no gyrocompass was available. Magnetic heading was used to provide the rotational aiding discussed above and to orient the vessel's image on the graphics CRT screen. Since the undetermined deviation would bias the measurements, magnetic heading was not selected as an input to the Kalman filter algorithm. Figure 8 shows the equipment setup aboard the J.P. IX.

Accuracy tests were conducted along test courses in two separate areas of the St. Marys River. Each course consisted of three marker buoys positioned to provide two straight segments and the included turn. Test Area One, near Ninemile Point in the lower river, was in the vicinity of the monitor station. Test Area Two, near Birch Point in the upper river, was farther away from the monitor.

Figure 9 is a plot of off-track distance for one test run. The break at the ten-minute mark is where the turn is started and off-track distance is referenced to the second segment rather than the first segment. In Test Area Two, 95 percent of the user equipment's off-track indications were within 37 feet of the Mini-Ranger value. In Test Area One, the 95 percent point is 47 feet. Along-track performance was also studied. In Area Two, 95 percent of the along-track indications were within 59 feet of Mini-Ranger. For Area

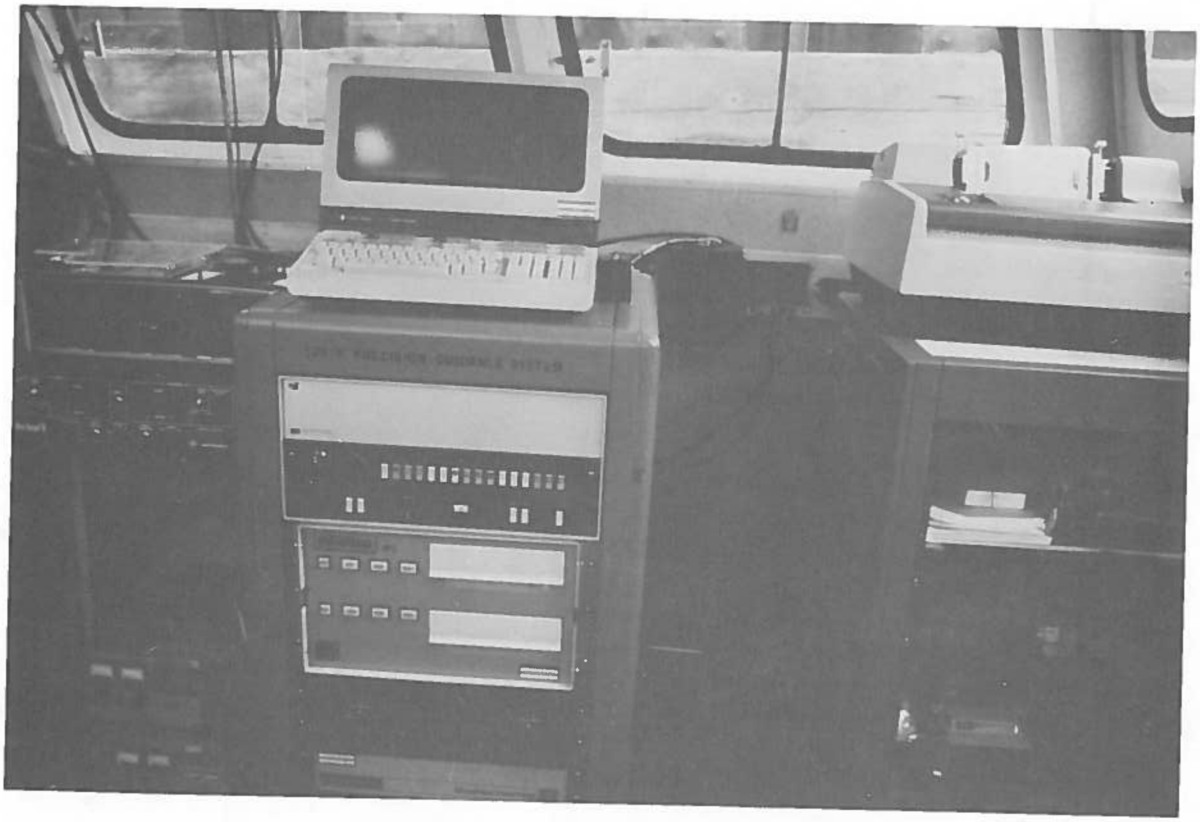

FIGURE 8   EQUIPMENT SETUP ABOARD THE J.P. IX

The transmitting and monitor equipment has established a repeatable time difference grid over a localized area. Before the mini-chain is made operational, the stability of the grid must be verified.

PROJECT STATUS

The Coast Guard's test and evaluation of the mini-chain is expected to continue through 1980. Beginning this winter, continuous time difference and time-of-arrival data will be collected at several sites to evaluate grid stability.

Efforts are in progress to develop a next generation of user equipment incorporating suggestions gathered during the ore carrier evaluation. The main intent is to construct a system which lends itself more readily to commercialization than does the existing user equipment.

The Coast Guard, pending the final results of the system evaluation and funding to improve the reliability of the ground station equipment, is considering changing the experimental status of the mini-chain to an operational status in 1981.

OMEGA - WORLDWIDE CALIBRATION AND VALIDATION

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OMEGA - WORLDWIDE CALIBRATION AND VALIDATION

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ABSTRACT: The OMEGA Navigation System is a (VLF) system operating between 10-14 kHz which will enable navigators to obtain positional data on a nearly worldwide and continuous basis when the system is in full operation with eight transmitting stations. Although the system is not yet complete and fully operational, navigation coverage is now available over large portions of the earth's surface. An important element in the operational development of the system is the collection of phase and signal-to-noise values through a worldwide network of fixed monitors. The data obtained from actual users and special studies will be combined with the fixed monitor data for an overall analysis of the system. The OMEGA monitoring program, the study of predicted and observed coverage and other steps in a signal validation program are necessary to provide the navigator with an effective OMEGA Navigation System.

INTRODUCTION

The OMEGA system, operating at various VLF frequencies between 10 and 14 kHz, is unique in that only eight transmitting stations are required to provide a nearly worldwide position locating service for all maritime and aviation users. Although seven of the eight permanent stations are now providing useful navigation signals, the system will not be declared fully operational until a validation program is completed. The validation program is being conducted to define the system's coverage and accuracy. Design of the eighth station in Australia started in 1977 with on-air operation anticipated in late 1980 or early 1981. The locations of the other seven stations are: Norway, Liberia, Hawaii, North Dakota, La Reunion Island (French territory in the Indian Ocean), Argentina and Japan.

A 1966 report[1] set the stage for implementation of the OMEGA Navigation System. Previous U.S. Navy R and D tests had demonstrated that a worldwide

1 Pierce, J.A. et al "OMEGA a World-Wide Navigation System-System Specification and Implementation" Office of Naval Research, Pickard and Burns, 1 May 1966, AD-630-900.

an accuracy better than 0.1 cycle. Compensation for these phase variations is made through use of corrections obtained from a propagation model. This propagation model is based on a series of equations accounting for such factors as solar illumination, geomagnetic orientation, surface conductivity and other geophysical phenomena. The model[2], developed by E.R. Swanson of the Naval Ocean Systems Center (NOSC), San Diego, California, is semi-empirical in nature since the coefficients of various terms within the equations can be adjusted through a regression of measured phase values obtained at various OMEGA monitor facilities. An important point to consider is that this model is dependent on a first order mode of wave propagation being dominant over higher order modes. To examine the propagation of VLF signals it is probably convenient to think of the electromagnetic energy transmitted by OMEGA stations to be guided between the ionosphere and the earth's surface. In this approach, natural resonant modes within a wave-guide are considered rather than the "rays" or "hops" that are used to illustrate skywave propagation in systems such as LORAN. From the situation illustrated in Figure 1, we can see there are two resonant modes being propagated. These are Transverse Magnetic (TM) modes which have an electric field component in the direction of propagation. Each mode will also have a characteristic propagation velocity and rate of attenuation. The mode sum at any point within the waveguide will determine the amplitude and phase of the signal detected by a receiver.

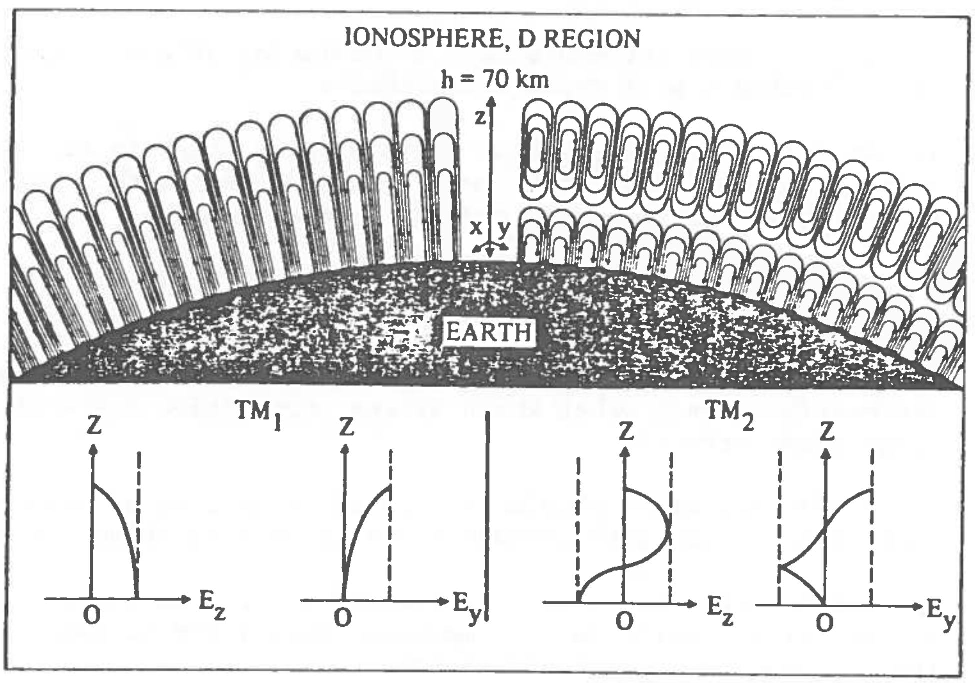

Figure 1 Modes of Propagation

[2] Morris, P.B. and Cha, M.Y., "OMEGA Propagation Corrections: Background and Computation Algorithm" Omega Navigation System Operations Detail, December 1974, AD-008-424

The eventual choice for an OMEGA monitor site location takes into consideration the availability of cooperating entities and facilities for a fixed site operation. Cooperation both nationally and internationally has been outstanding in this program. The OMEGA monitor facility network currently (September 1978) in operation is as follows:

- Hestmona, Norway
- Farnborough, U.K.
- *Stornoway, U.K.
- Sardinia, Italy
- Nea Makri, Greece
- Lajes, Asores
- Piarco, Trinidad
- Fort Walton Beach, Florida, USA
- Bermuda, U.K.
- Resolute, Canada
- Inuvik, Canada
- Frobisher Bay, Canada
- *Ottawa, Canada
- Dickey, North Dakota, USA
- Sabana Seca, Puerto Rico
- Makapuu Point, Hawaii, USA
- Tsushima, Japan
- *Miyako Jima, Japan
- Diego Garcia
- Djakarta, Indonesia
- Seattle, Washington, USA
- St. Anthony, Newfoundland
- Anchorage, Alaska, USA
- Arequipa, Peru
- Hokkaido, Japan
- *Soya, Japan
- *Oshima, Japan
- Buenos Aires, Argentina
- Trelew, Argentina
- Reading, Massachusetts, USA
- Monrovia, Liberia
- Reunion Island, France
- Belem, Brazil
- Recife, Brazil
- Keflavik, Iceland
- San Diego, California, USA
- Clark AFB, Philippines
- Orote Point, Guam
- Portsmouth, Virginia, USA
- Pago Pago, Samoa
- *Toulon, France
- Darwin, Australia
- Marcus Island, Japan
- *Dania, Florida, USA
- Canary Islands
- Adak, Alaska
- Canal Zone, Panama
- Kure, Midway

*Indicates Cooperative Data Exchange (Not U.S. Coast Guard Initiated)

ESTABLISHMENT OF A DATA BASE FOR SYSTEM VALIDATION

Once a reliable network of monitor facilities is established, calibration of the system can be undertaken to improve its accuracy but this is a somewhat lengthy process. Because immediate requirements for worldwide electronic navigation exist, an accelerated program of System Validation has been initiated. Again this program is designed to specifically define OMEGA coverage and accuracy, hence determining its capabilities and limitations. The problem is to establish a solid data base rapidly which will perform this function.

The fixed monitor network as it is expanded plays a very important role in this program since many hours of repeatable data can be obtained. Assessments as to the stability of the signal, whether or not it is below receiver tracking thresholds and the accuracy of the navigator's propagation correction tables can be made. However, many fixed monitors could be required in a large OMEGA coverage area since propagational errors are only correlated over 3 megameters and facilities may not be available in all parts of the world to support their operation. Mobile monitors such as ships and aircraft can be used to collect similar data but due to the phase shift induced on the signal by a moving platform, special interpretation problems present themselves without an accurate geographic reference. The fairly large errors in propagation correction models and navigator's tables can be identified, however, if the geographic reference system is fairly accurate. An aircraft with a well calibrated inertial system, occasionally updated by an accurate ground reference, will probably suffice; a shipboard operation will require a reference such as the Navy Navigation Satellite System (NNSS). Such mobile observation platforms play an important part in areas where the fixed monitoring network is essentially incomplete.

Controlled flight tests are also required to define possible areas of modal interference within the OMEGA coverage area. As was pointed out previously, knowledge of modal interference is important to the navigator since it may be significant enough to make some signals unusable during nighttime conditions. The detection of large phase deviations or "lane jumps" is possible at a fixed ground monitor but locating the boundaries of a modal interference zone would require a multitude of monitors. Because of this situation, and rapidly changing conditions along the propagational path, a fast flying aircraft is required.

In completing the data base, navigator's reports provide important evaluation data which reflect actual operating conditions rather than controlled ones. In most cases an accurate reference system is not available for making comparisons hence the data is of limited value. Still, this information is useful as an insight to operational problems that may be encountered with the system, and therefore, should be included in the overall evaluation.

Data from the monitor network is edited for errors and then retained in a master data bank at ONSOD. This phase and signal-to-noise ratio data is then used for coverage analysis and accuracy improvements. For a given monitor location six lines of position are computed for updating the phase prediction model when appropriate. Operational reports from various maritime and airborne sources are not computerized at this point but are

Program should be an effective OMEGA Navigation System for both the marine and airborne user.

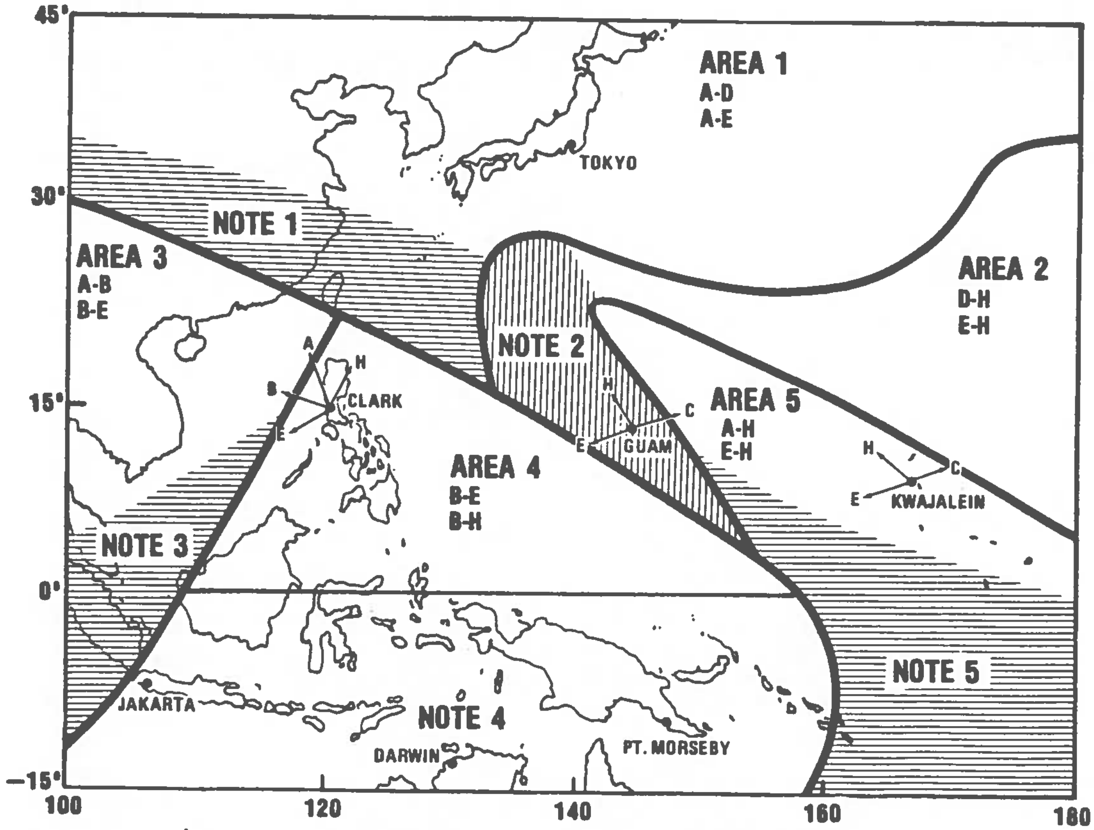

Figure 3 Recommended LOP's for Western Pacific Regions Based on Validation Results

A OMEGA Norway
B OMEGA Liberia
C OMEGA Hawaii
D OMEGA North Dakota
E OMEGA La Reunion
H OMEGA Japan

Arrows indicate direction for which signals are received.

Note 1: H can be used as an alternate for D during local daytime in shaded area.

Note 2: C can be used as an alternate for D during local daytime in shaded area.

Note 3: H can be used as an alternate for A during local daytime in shaded area.

Note 4: Alternate stations are not required in Area 4 when the recommended station B, E and H are available.

Note 5: C can be used as an alternate for A during local daytime.

VOR/DME REPLACEMENT AND UPDATE PROGRAM

Edmund P. Kennedy, Chief
Navaids/Communications
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VOR/DME REPLACEMENT AND UPDATE PROGRAM

Edmund P. Kennedy, Division Chief

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ABSTRACT. This paper provides current status of the VOR/DME replacement program and the introduction of Remote Maintenance Monitoring techniques. It highlights the type of procurement and methodology, the magnitude of the program, the goals and objectives of the replacement program, the RMM concept and significant milestones.

I plan to provide you with a current status report on the FAA's VORTAC Improvement/Replacement program commonly referred to as the Second Generation VORTAC program. As we will see in a minute, it actually upgrades VORs, VORTACs, and VOR/DME basically in the same configurations and population mix that exists today.

The technical specification requires completely solid-state equipment with fully integrated Remote Maintenance Monitoring capability.

It is proposed to retain the standard VORTAC building structure intact. This will accommodate the Second Generation equipment which, of course, takes up much less space than the equipment presently installed. In fact, the building will be excessive for our needs, but it is still not economical to replace the present building as we own it, and it is relatively cost free. For example support equipments like air-conditioning and standby power systems will be either replaced or if possible, modularly reduced in size and/or capacity.

The only existing rack that will be retained is the TACAN antenna speed control rack which is virtually maintenance and outage free. The current antenna systems will possibly be retained as current, state-of-the-art improvements are not materially beneficial over our present systems which are vintage technology of the 1950's.

Slide #1 may provide, no doubt, absolutely no new knowledge to anyone in this room. However, the acronyms VORTAC, DME, et al, have such common use they have assumed the status of dictionary words, so it might serve some purpose to refresh memories as to what they actually represent.

V ERY HIGH FREQUENCY
O MNIDIRECTIONAL
R ANGE
T
A } TACTICAL
C
A IR
N AVIGATION
D ISTANCE
M EASURING
E QUIPMENT

VORTAC – THE FOUNDATION OF THE PRESENT-DAY AIRWAY SYSTEM, PROVIDING BEARING AND DISTANCE INFORMATION FOR RADIO NAVIGATION BY CIVIL AND MILITARY AIRCRAFT.

SLIDE 1

Background

PRESENT SYSTEM CONSIST OF 920 VORS AND 720 TACANS

EQUIPMENT VINTAGE		POPULATION (PERCENT)
VOR	1943 - 1946	35
	1951 - 1956	27
	1957 - 1962	38
TACAN BEACONS		
	1957 - 1959	42
	1960	58
TACAN MONITORS		
	1957	33
	1960	45
	1968	22
VOR/VORTAC SYSTEM COST OF OPERATION		$37M/YR

SLIDE 3

Program Goal

CONTINUE OPERATION OF VOR/VORTAC SYSTEM THROUGH YEAR 1995 (AND BEYOND) WITH:

- HIGH LEVEL OF RELIABILITY/AVAILABILITY
- GREATLY REDUCED COST OF OPERATION:
  - REDUCED STAFFING
  - ENERGY SAVINGS
  - LOGISTICS (SUPPLY SUPPORT) SAVINGS
- AMORTIZED INVESTMENT WITH EARLY PAYBACK

SLIDE 5

SIGNIFICANT MILESTONES

SPECIFICATION PREPARED AND APPROVED	2/78
ACQUISITION PAPER APPROVED	4/78
RFP ISSUED	4/78
CONTRACT AWARD	2/79
DELIVERY OF FIRST ITEM	11/80
FINAL DELIVERY	8/84

SLIDE 7

LORAN-C PROPAGATION RESEARCH

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LORAN-C SIGNAL ANALYSIS EXPERIMENTS*
"AN OVERVIEW"

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Washington, D.C. 20590

ABSTRACT. This paper presents an overview of the preliminary observations for three experiments that were conducted as part of the U.S. Coast Guard Loran-C Signal Analysis Project. The fundamental objective of the experimental program is to determine whether Loran-C can provide an all weather, continuous navigation aid for piloting the restricted waters of harbors and harbor entrances (HHE). To achieve this objective, a data collection effort is well underway to determine the limits on accuracy of Loran-C for harbor and harbor entrance navigation and to investigate the fundamental causes for these limits. Three key experiments have been completed. These experiments and associated objectives are:

1. Loran-C Stability Experiment — To determine the source, magnitude, and frequency of occurrence of Loran-C timing fluctuations in a service area.

2. Propagation Experiment — To evaluate techniques that may be used to improve groundwave propagation prediction models. Measurements were made over several propagation paths and compared with calculated values using propagation prediction models.

3. San Francisco Harbor Experiment — To study spatial distortions in a harbor and harbor entrance environment. Measurements were made at several fixed sites and on board a vessel in the San Francisco harbor and harbor entrance. The data are being used to analyze the accuracy of Loran-C.

THE STABILITY EXPERIMENT

To assess Loran-C's potential for high accuracy navigation, a combination of theoretical analysis and experimental results have been used to separate and quantify error sources. The three categories of error sources considered are: receiver-induced fluctuations, transmitting equipment fluctuations, and propagation fluctuations. The stability experiment has been designed to yield the magnitude, source, and frequency of occurrence of errors produced by the above

*Presented by Lt. Cdr. Andrew J. Sedlock, USCG Headquarters.

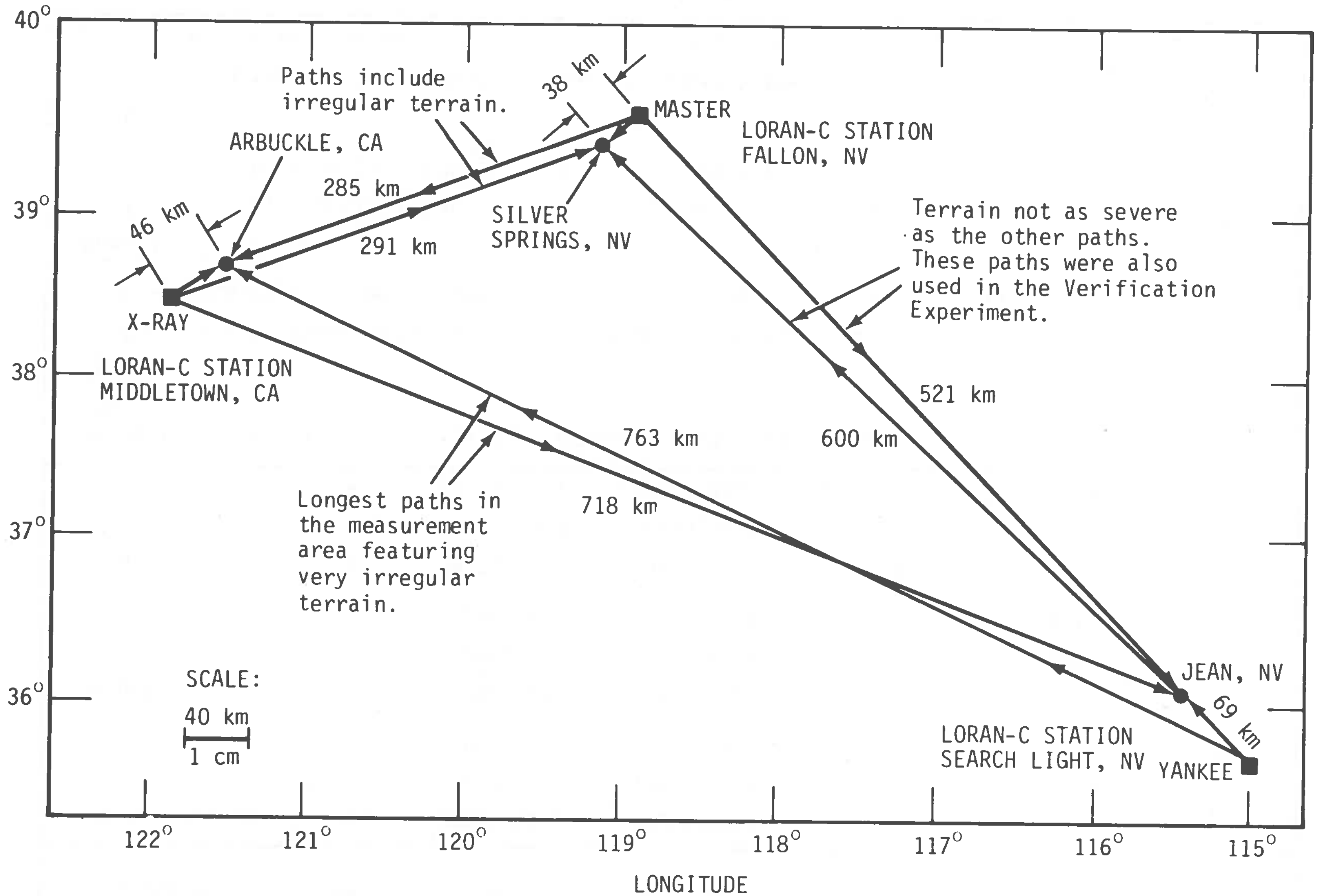

Figure 1 Stability Experiment measurement sites, transmitter locations, and signal paths.

Table 2 Stability Experiment data summary for January 1978.

Location	Week	Mean TDX	Mean TDY	Std. Dev. TDX rms	Std. Dev. TDY rms	Data Sample (days)
Silver Springs	2	28933.7898	43842.2219	0.0276	0.0204	4
	3	28933.7179	43842.211	0.030	0.013	1
Arbuckle	2	27296.202	43565.470	0.020	0.015	4
	3	27296.179	43565.489	0.014	0.021	1
Jean	2	28752.1946	40455.9711	0.024	0.0232	4
	3	28752.157	40456.026	0.024	0.008	1

Standard Deviations (data from Silver Springs, Arbuckle, and Jean) of the instantaneous fluctuations rms

Week 1

X - Chain Fluctuations 0.0223 X - Propagation Fluctuations 0.0114

Y - Chain Fluctuations 0.0160 Y - Propagation Fluctuations 0.0104

Week 2

X - Chain Fluctuations 0.0178 X - Propagation Fluctuations 0.0148

Y - Chain Fluctuations 0.0137 Y - Propagation Fluctuations 0.0094 propagation fluctuations for Jean and Arbuckle, also shown in Table 3, are all less than 23 nanoseconds rms.

Seasonal Changes

A TD and TOA receiver were placed at Ft. Cronkhite (near the entrance of the San Francisco Harbor) and data were collected from August 3, 1977, through May 10, 1978. The purpose of these measurements was to obtain a measure of the seasonal variations. Data collected using the TOA receiver show small changes in the mean values from summer to winter (maximum value of about 15 nanoseconds) for both TDX and TDY. The TD receiver shows less than 60-nanosecond changes in mean values from summer to winter for TDX and TDY. No discernible seasonal effect has been found in the Ft. Cronkhite data. However, the Ft. Cronkhite measurement site is only about 100 miles north of the system area monitor (located in Point Pinos, California). It is reasonable to expect smaller changes in TD when the measurement site is located near the system area monitor. We have not determined what the long term change in TD would be if an additional receiver had been located further from the system area monitor (such as San Diego, CA).

STABILITY EXPERIMENT CONCLUSION

The Loran-C signal in the measurement area located in the Southern Triad of the West Coast Loran-C chain is very stable. Standard deviations (in nanoseconds) of baseline fluctuations measured in December 1977, and January 1978, are:

Baseline	Equipment	Propagation
X	23.7	18.3
Y	19.0	11.5

THE PROPAGATION EXPERIMENT

One of the objectives of the Loran-C Signal Analysis project is to improve the accuracy and control of Loran-C through a better understanding of Loran-C signal characteristics. An important step in achieving this objective is to better define the predictability of the Loran-C signal phase and amplitude characteristics and to explain differences between observed time differences (TDs) and predicted TDs using current prediction and calibration techniques.

Four groundwave propagation prediction models or techniques have been reviewed and tested against each other and against a carefully controlled experimental data base by Gambill and Schwartz (Reference 2). This work was summarized by Samaddar (Reference 3). The four techniques are:

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[2] Gambill, B., Jr., and K. Schwartz, "Loran-C Signal Analysis: Propagation Model Evaluation Final Report," GE78TMP-51, May 1978.

[3] Samaddar, Suren Nath, "The Theory of Loran-C Groundwave Propagation — A Review," presented at URSI Conference, Helsinki, Finland, August 1978 (to be published).

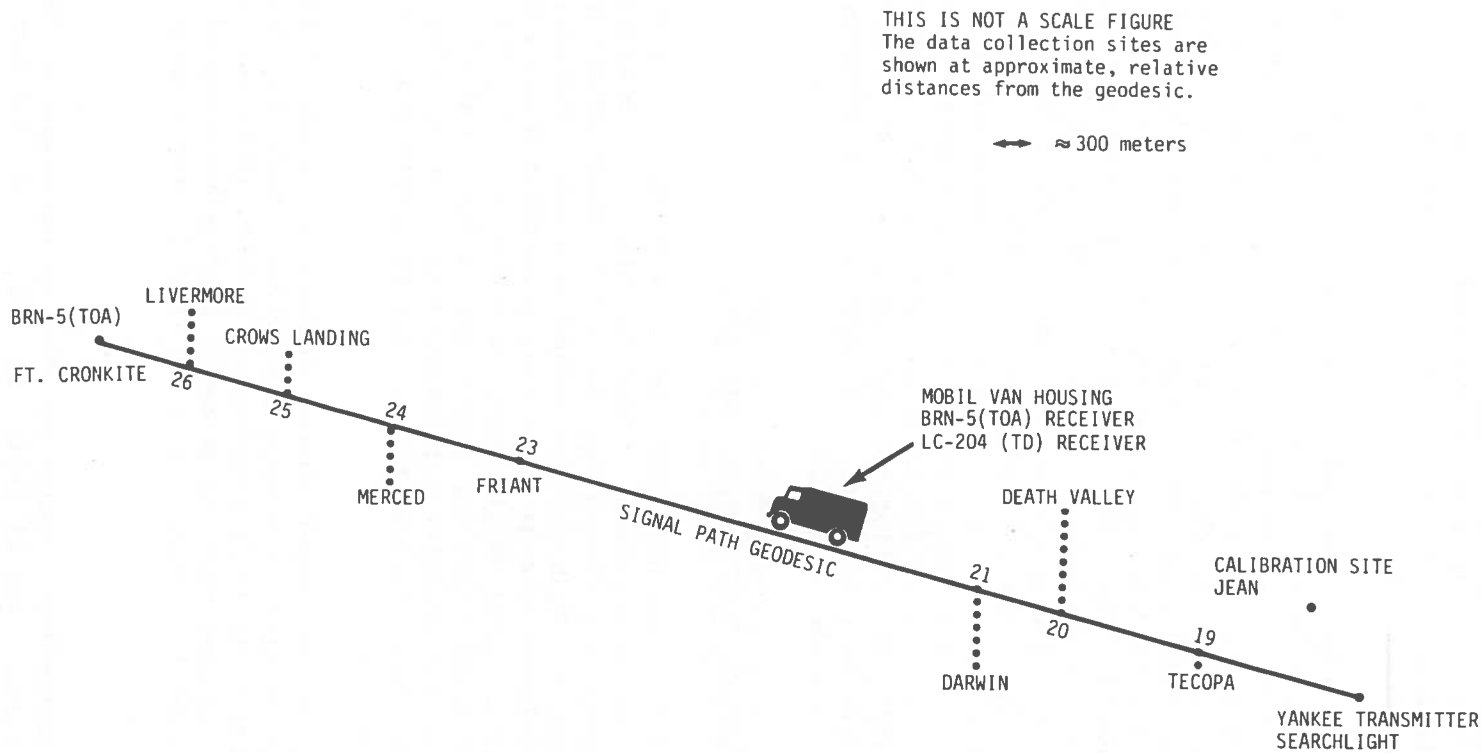

Figure 2   Propagation path data collection sites relative to the GEODESIC.

program by Johler and Berry (Reference 6) to incorporate a continuous change in surface impedance and terrain.

Both Millington's method and the Integral Equation technique require surface impedance as an input parameter. The initial approach was to calculate and use the same surface impedance in both programs (Millington and Integral Equation technique) from geological data. Geologic maps were used to estimate the type of soil and rock as a function of distance along the path. For each material type, a range of conductivity values was determined from the radio resistivity summaries provided by Keller and Frischknecht (Reference 7). The dielectric constant is determined by the type and fractions of the materials in the soil or rocks. Three layers of different rock and soil types were used to calculate the surface impedance.

Unlike Millington's technique, the Integral Equation method also takes into account irregular terrain along the path. The terrain (altitude) profile along the propagation path was obtained from USGS 7.5-minute and 15-minute topographic maps covering the entire path. Points along the geodesic from Searchlight to Ft. Cronkhite were obtained using the Sodano method. These points were corrected from WGS72 to NAD27 (to be compatible with the maps) using overlays provided by DMA (Defense Mapping Agency).

Figure 3 shows secondary phase versus distance (from Searchlight in km). Included on the horizontal scale are the town names nearest to the actual measurement sites. The smooth curve in Figure 3 shows calculations using Millington's Technique and accounts for only surface impedance along the propagation path. The fluctuating curve is calculated using the Integral Equation approach which includes the effects of both surface impedance and irregular terrain along the path. In both of these models, the above-mentioned calculated surface impedance was used as an input. The bars in Figure 3 represent the uncertainty in the measured data, and are shown for each measurement site (shown on the horizontal scale). The experimental data are referenced to the predicted value at Tecopa. The initial test calculations for the propagation path were made using the input data exactly as it had been derived. It can be clearly seen that terrain (elevation change) is an important factor which increases secondary phase considerably. When the terrain is suppressed in the Integral Equation programs, the agreement between the Integral Equation and Millington methods is almost exact, as shown in Gambill and Schwartz (Reference 2).

A procedure similar to the U.S. Coast Guard technique for optimizing impedance maps was used to adjust the impedance to minimize the standard deviation between predicted and measured value at the first seven measurement sites. Since the measured results include the effect of both terrain and surface impedance, optimization of the surface impedance using Millington's technique implies that an equivalent impedance can be defined that compensates for

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[6] Johler, J.R., and L.A. Berry, "Loran-C Phase Corrections Over Inhomogeneous Irregular Terrain," ESSA Tech. Report IER59-ITSA-56, 1967.

[7] Keller, G.V., and F.C. Frischknecht, "Electrical Methods in Geophysical Prospecting," Pergamon Press, 1966, (Reprinted 1977).

terrain effects. In this procedure, the surface impedance of the segments is allowed to vary in an iterative calculation and impedance values are determined that minimize the rms error between measured and predicted results. Figure 4 shows secondary phase predictions with the impedance optimized (shown as filled circles). The results indicate that impedance adjustment can be used to compensate for terrain-induced variations. Further optimization of impedance values using the Millington technique would result in identical values between measured and calculated values.

It is well known that the additive phase depends strongly on the estimate of the surface and subsurface conductivity. To quantify the sensitivity for the path considered in the experiment, a set of calculations was performed by Gambill and Schwartz (Reference 2) where all values of the conductivity were decreased by a factor of two. This has a negligible effect for those regions where the conductivity is very high (like seawater) but has a large integrated effect in the low and intermediate conductivity regions. There is an immediate ∿350-nanosecond increase in the computed phase at Tecopa and an 800-nanosecond increase at Livermore and Ft. Cronkhite. The computed secondary phase for this case is also shown in Figure 4 (upper curve). Note that the upper curve (decreased conductivity) and the original prediction (lower curve) bracket nearly all the experimental data. Small adjustments in the choice of material conductivity could be used to make the theory and experiment match.

PROPAGATION PATH EXPERIMENT CONCLUSIONS

A comprehensive list of conclusions and a sensitivity analysis for all four prediction techniques is provided by Gambill and Schwartz (Reference 2). A summary of conclusions for this experiment is presented here:

1. Millington's technique and the Integral Equation technique give nearly identical results for a highly inhomogeneous impedance path when the terrain variations are suppressed for the integral equation calculations. Those variations which are observed are most probably due to the finer detail of the surface impedance data for the integral equation test calculation. Thus, Millington's technique is adequate where terrain variations are not important.

2. The effect of significant terrain variations (in this case, large elevations above the mean geoid) is to increase the secondary phase, which also implies increase in equivalent surface impedance.

3. Based on integral equation calculations, both terrain and surface impedance variations are important in predicting secondary phase for the propagation path.

4. Low and intermediate values of conductivity must be known to a greater accuracy, since phase is more sensitive to the change in conductivity in this range.

5. Experimental data error bars are ±50 nanoseconds, indicating the experimental technique was successful.

6. Differences between the theoretically predicted and measured incremental phase changes, using the original models (using calculated impedance) for the terrain and surface impedance profiles, ranged from tens of nanoseconds to half a microsecond. Predicted values can be adjusted to match this particular experimental data by changing the surface impedance less than a factor of $\sqrt{2}$.

7. Data (geologic and terrain) preparation is a formidable task and computation time is very long when using the integral equation method.

THE SAN FRANCISCO HARBOR EXPERIMENT

The San Francisco Harbor Experiment is a key experiment in the Loran-C Signal Analysis Project. This experiment was completed in May 1978, and has provided the first segment of data necessary to begin the evaluation for the potential use of Loran-C for high accuracy all-weather navigation in a harbor and harbor entrance environment (HHE). Three modes of operation—normal, repeatable, and differential—are under investigation. Some results from the harbor experiment are available and will be presented.

The specific objectives of this experiment are to compare: (1) the predicted grid with the measured results that include spatially distorted contours and phase tables (and as a by-product a measurement technique for harbor calibration), and (2) the data necessary for assessing the performance of Loran-C in the normal, repeatable, and differential modes.

Configuration

The harbor measurements are divided into two sets: one set was made at various fixed sites around the periphery of the harbor, and another set was made on board the U.S. Geological Survey Research Vessel Polaris. Results obtained from the Loran-C fixed sites will be discussed first.

Fixed Site Data

Five TD receivers were rotated in San Francisco Harbor to different sites three times. These three deployments or sets are shown in Figure 5. As a first approximation for planning the experiment, we assumed that spatial variations in the harbor are primarily the result of signal variations produced near the harbor, specifically, the variation in the length of the overwater portion of the path and the scattering due to bridges. This assumption, coupled with data analyzed from Ft. Cronkhite and Treasure Island,* produced the rationale for fixed site selection and vessel tracks shown in Figure 5. Details are described by Illgen, Gambill, and Nelson (Reference 8).

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[8] Illgen, J.D., B. Gambill, L. Nelson, "Harbor Experiment Analysis Plan," February 14, 1978.

*During the calibration of the West Coast chain, the USCG collected data at Treasure Island.

Fixed Site Data Analysis

Table 4 presents the means and standard deviations obtained for deployments 1, 2, and 3. The values in Table 4 were computed using 7 to 9 days of data (data sampling interval of 100 seconds) for each site (the actual number of days of data for each site is indicated under the data sample column in Table 4). All standard deviations in Table 4 are small (below 30 nanoseconds). The fixed site data shown in Table 4 will be used in conjunction with the vessel data to determine the effects of spatial distortion in the harbor. This will be the subject of a future paper.

Vessel Measurements in the Harbor

While measurements were being made at fixed sites, data were also collected on board a vessel in the harbor and harbor entrance. A TOA and TD receiver provided the data collected on board the vessel. The vessel measurements will provide a good indication of the variations due to spatial distortions. The data are currently being used in conjunction with the data measured at fixed sites to examine the following:

1. Phase recovery along X, Y, and M paths (as the seawater portion of the path varies).

2. Spatial variations seen along the main shipping lanes and variations due to three bridge structures as a function of distance from the bridge structures.

3. Spatial variations between measurement sites, and differences between measurements taken on the vessel and on nearby land sites, i.e., the effect of taking measurements at points on land and on the water very near the land/sea interface.

4. The magnitude of spatial distortions in the inner harbor area. Data taken as the vessel steams along an "inner loop" in the harbor (about 200 to 500 yards into the bay from the outer edge of the channel, see Figure 5) will provide these measurements.

Vessel Position

Vessel position was measured quite accurately using the Trisponder radar system. The vessel position measurements should be an order of magnitude better than expected Loran-C errors to reasonably measure any biases in the Loran data. Summer data collected at Ft. Cronkhite had demonstrated a 30-meter (2-D rms) Loran-C error. This dictates a requirement of a 3-meter (2-D rms) error in locating the vessel. To date, it appears the Trisponder radar system (a Master unit and track plotter on the vessel and four transponders on the shore) provided this accuracy.

Preliminary Observations

Data reduction, processing, and analysis are currently being completed. Therefore, only a few preliminary observations will be made about the vessel measurements:

1. Severe fluctuations in excess of 1 μsec occurred near (300 yards) and under the Golden Gate Bridge.

2. 200- to 500-nanosecond fluctuations occurred directly under the Oakland Bay Bridge (the TD receiver showed low signal on Y only).

3. No discernible effects have appeared to date in the measurements when the vessel steamed near and under the Richmond bridge in contrast to the Golden Gate and Oakland Bay Bridge results.

The vessel and fixed site data are being processed to provide the effects of spatial distortion. 1-μsec grids of the harbor are being prepared. To attain additional resolution, a phase table is being generated for each grid that can be interpolated for accurate phase values at specific locations in the harbor.

Differential Loran-C

There are three Loran-C modes of operation that may provide accurate navigation in confined waters. These are: Differential Loran-C, Mini Loran-C, and Auxilliary Low-Power Transmitters. The Loran-C Signal Analysis Project has included the assessment of Differential Loran-C. For this augmentation technique, Loran-C signals are monitored at a fixed site, and the TD at the monitor site can be compared with a reference TD for the monitor site. A correction can then be computed and transmitted to users. This technique, whereby real time corrections are applied to Loran-C TD readings, has been shown by Goddard (Reference 9) to provide improved accuracy dating back to 1973.

Differential error calculations (see Nelson, Reference 10, for calculation's method) have been made for several sites (one site correcting another in various combinations) in San Francisco Harbor. The analysis is not yet complete. Initial results are:

1. Improvements of about 5 feet (corresponding improvement ratio of about 1.1) to 8 feet (corresponding improvement ratio of about 1.3) for correction intervals of 100 seconds, 15 minutes, and 2 hours are typical for sites in Figure 5.

2. As expected, very little improvement occurs for correction intervals of 6 hours and 24 hours.

In interpreting the above results, it must be recalled that the standard deviations in Table 4 are small. The measurement sites in San Francisco are located near the system area monitor as mentioned previously. The system area monitor is providing the information to initiate local phase adjustments (or

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[9] Goddard, R.B., "Differential Loran-C Time Stability Study," CG-D-80-74, Office of Research and Development, Department of Transportation, U.S. Coast Guard, Washington, D.C., November 1973.

[10] Nelson, L.W., "Loran-C Signal Analysis: System Analysis Interim Report No. 1," GE77TMP-54, December 1977.

GPS LOW COST RECEIVER AND ANTENNA EFFORTS

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Management, FAA

GPS LOW COST RECEIVER AND ANTENNA EFFORTS

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Federal Aviation Administration
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ABSTRACT. The Federal Aviation Administration's investigation of low cost user equipment for utilization of the Global Positioning System by general aviation will be reviewed. The results of a design study to evaluate the performance of a basic IFR navigation receiver using today's technology are discussed in some detail. A more esoteric design using advanced technology is also presented and the technology developments needed to meet that design are indicated.

INTRODUCTION

Considerable attention is being given to the potential utilization of the Global Positioning System (GPS) as a civil navigation system. The appeal of a single, world-wide navigation systems is hard to resist. But the transition from theory to practice is quite often not an easy one. In the case of civil aviation, a principal area of concern is the development of a low-cost GPS receiver suitable for single pilot operation in general aviation aircraft. It is the intent of this paper to discuss the FAA's efforts to evaluate the feasibility of developing just such a receiver.

Before that discussion begins, however, it is necessary to view GPS in its proper perspective. First, it should be noted that GPS was not designed with civil navigation as a primary goal. Rather, it is intended to be part of DOD's overall weapons delivery capability. The satellite orbits, power levels, and signal structure were selected to meet this objective. The cost goals established by DOD for GPS user equipment are considerably different than those believed necessary for civil users, i.e. at least an order of magnitude lower than those of DOD.

This, in essence, is the problem facing the FAA. Can a simple, reliable, and economical GPS receiver be developed for general aviation? To answer this question the FAA has initiated an investigation into the design and development of a GPS receiver for use by general aviation. The initial results of that investigation are discussed below.

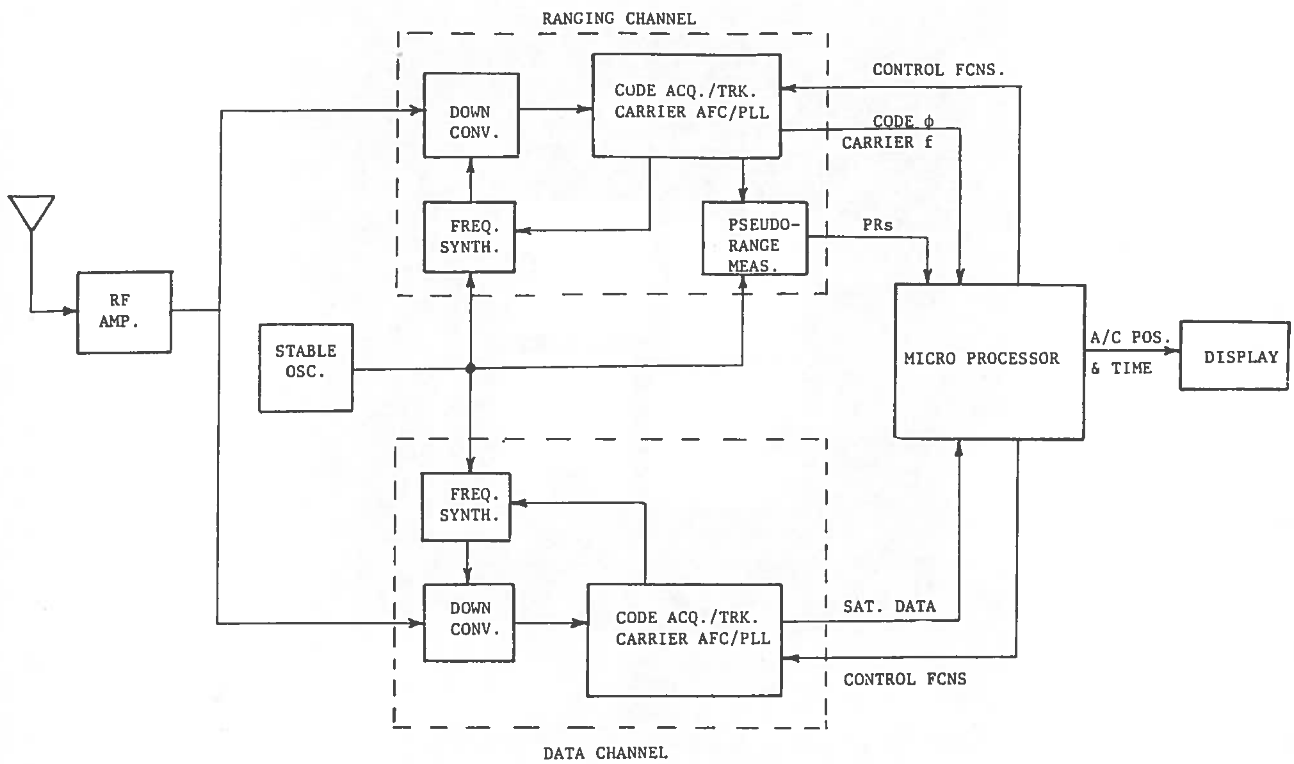

FIGURE 1 BLOCK DIAGRAM OF TWO CHANNEL GPS RECEIVER

The two-channel design was chosen in order to maintain a high update for the navigation function in an IFR environment. A single channel version which may be suitable for the VFR environment has also been investigated. In the latter the receiver would alternate between the navigation and data collection functions. Data collection for transitioning to new satellites or updating data for those currently in use would occur only for short intervals (1-5 min, every 0.5-2 hours). Position updates would occur at a reduced rate (one/minute) in this interval, but a pilot would have an override option for controlling entry into this mode.

LOW COST GPS ANTENNA INVESTIGATION

A major area of concern with regard to the use of GPS by general aviation has been the availability of a suitable antenna. The FAA, through the Transportation Systems Center (TSC), has been investigating aircraft antennas for use with satellite systems for several years. The most promising concept for GPS appears to be a simple microstrip crossed slot antenna on a flexible substrate. Figure 2 is an example of an antenna developed by the Ball Aerospace Systems Division using this technique. A typical pattern for this type of antenna is shown in Figure 3.

The main problem associated with a GPS antenna for general aviation is the radiation pattern once it is installed on board an aircraft. General aviation aircraft come in all sizes and shapes which may result in a unique pattern for each aircraft type. In an effort to determine the suitability of of the antenna described above, the FAA has elicited the support of NASA's Langley Research Center. It is our intent to have developed a scale model of the antenna for installation on several general aviation aircraft models at Langley and to evaluate its expected performance. Until those tests are completed, the question of a simple, low cost GPS antenna for general aviation remains unresolved.

THE "IDEAL" GPS RECEIVER

Although we have just described a receiver which appears to meet the needs of general aviation, the question remains "Is this the receiver which should be developed?" The answer is "probably not." Assuming a reasonable advance in the state-of-the-art in the next several years, particularly in LSI, it is believed that a much different receiver design would evolve. The reasons for this are as follows:

- A continous receiver, i.e., one which simultaneously tracks the GPS spacecraft, will perform better than a sequential one.
- An aided receiver, i.e., one in which altimeter heading, and time information is utilized by the microprocessor, will have better performance than an unaided one.
- Operationally, a receiver which uses coded way points instead of latitude and longitude will facilitate single pilot operation.

To reach this "ideal" state of affairs, several significant advances in technology must obtain. First, and foremost, is the development of inexpensive RF LSI and, possibly, digital matched filters. Second, is the development of inexpensive encoding altimeters and directional gyros. A third would be the development of highly stable low cost oscillators. The technology for using coded waypoints exists today and is an interface problem rather than a development problem. It is our belief that government and industry should seriously investigate these technologies when considering the application of GPS to general aviation.

SUMMARY

The FAA efforts to evaluate the feasibility of using the Global Positioning System for civil navigation have been discussed. Those efforts are primarily directed at the development of low cost user equipment. The design of a receiver which appears to satisfy future navigation requirements and has potential for being developed at low cost using today's technology was reviewed. Finally, an "ideal" receiver was discussed and some direction provided for new technology developments which are needed to achieve that objective.

GPS ALTERNATIVE SIGNAL STRUCTURE

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GPS ALTERNATIVE SIGNAL STRUCTURE

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ABSTRACT: The present signal structure used in Phase I of the NAVSTAR GPS program has been selected for use in the Department of Defense based on military requirements for an auxiliary navigation facility to be operated in a hostile environment without particular emphasis on low cost design for user equipment.

This paper examines a generalized signal structure for possible changes to the Phase I signal which might decrease user equipment complexity and cost and increase operational utility for civil users.

Two specific examples are considered:

1. A burst PSK system.

2. The Phase I system with increased power and data rate.

1. INTRODUCTION

The NAVSTAR Global Positioning System (GPS), a navigation facility being developed by the U.S. Department of Defense, will consist of 24 satellites in 12 hour orbits, transmitting synchronized L band signals. The configuration of the constellation and the data transmitted permit a navigator to calculate his earth position coordinates, altitude and system time. A detailed description of the system may be found in reference (12) which includes, in turn, a complete set of references.

1.1 GPS Alternate Signal Structure

The Global Positioning System was designed to provide navigation information to military vehicles operating in a hostile environment. Since it was not designed for use as a primary navigation aid but as navigation update

1.3 Design Evaluation Criteria

Next, we list some of the performance factors which might be used in ranking the various signal structures:

Link Margin

Antenna (user)
Satellite Transmitter Power
RFI
Multipath

Receiver Design Complexity

Carrier Frequency and Code Search
Carrier Phase Lock and Code Lock
Oscillator Stability
User Dynamics
Acquisition of "New" Satellite Signal
Noise Figure

User Operating Procedures

Use as a Primary Navigation Aid (Coverage, Dynamics)
Operator Interaction with Equipment

We shall discuss the signal structure of the GPS system as presently conceived and discuss one example of the PN coded, phase-shift-keyed (PSK) burst, TDM system as an alternative signal.

2. GPS WAVEFORM AND GENERIC RECEIVER DESCRIPTION*

The description in this section is taken largely from references 6 through 8.

2.1 Waveform

Carrier frequencies for the present GPS system are L_1 = 1575.27 MHz and L_2 = 1227 MHz. The L_1 signal is BPSK modulated by two PN codes in phase quadrature, one at a 1.023 MHz chipping rate (the C/A signal) and one at 10.23 MHz chipping rate (the P signal). Superimposed is BPSK modulated data at 50 baud/sec. The L_2 signal duplicates the L_1 P signal, but at a lower power level.

Carrier, code and data are all derived from a common 5.115 MHz reference and are thus synchronized with each other. The C/A code length is 1 msec. The P code length is one week. The codes are satellite specific. A receiver

*This is taken from Reference 16

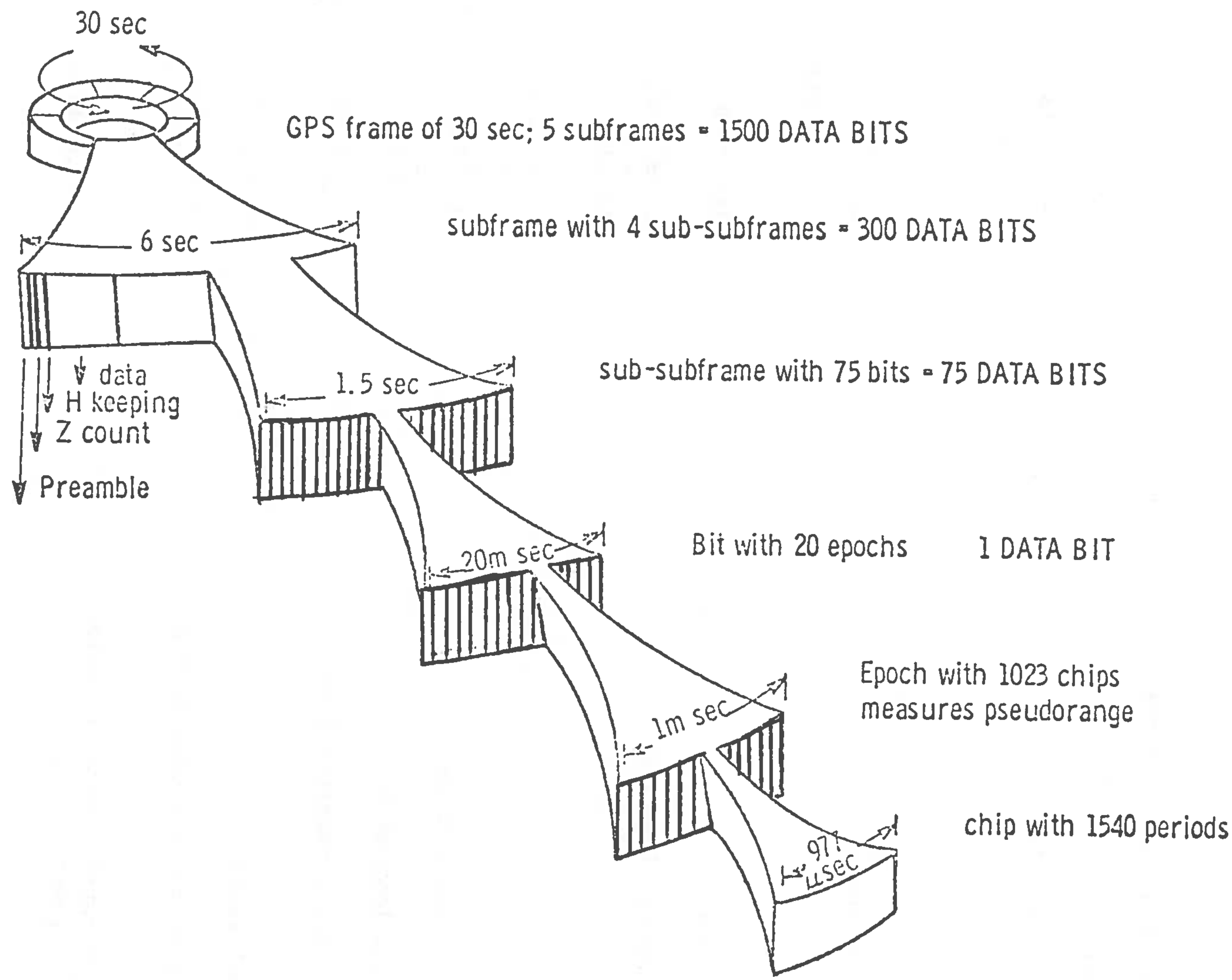

FIGURE 1 TIME STRUCTURE OF THE GPS SIGNAL

TABLE 2 ERROR SUMMARY*

Error Contribution	Pseudo-range	Delta-Range	Notes
Satellite Ephermeris	1.5 meter		Uncorrelated between Satellites Phase III.
Satellite Group and Clock	1.0 meter		Uncorrelated between Satellites Phase III.
Satellite Clock Noise		3×10^{-3} meter	Assumed Cesium clock and 0.5 second interval.
Pseudorange Noise	1.0 meter		Evaluated at C/N_0 = 30 dB for P-Code.
Range Quantization	0.27 meter		
Range Mechanization Error	1.0 meter		
Delta-Range Measurement Noise		6×10^{-3} meter	Evaluated at C/N_0 = 30 dB for P-Code
Delta-Range Quantization		3×10^{-3} meter	
Delta-Range Mechanization		0.1 meter	
Ionospheric Dual Frequency	3.0 meter		Evaluated at C/N_0 = 30 dB for P-Code. No Averaging.
Troposhperic Residual	1.0 meter		Evlauated at 5° elevation and zero altitude
Propagation Gradient		1.0×10^{-2} meter	Spatial and temporal decorrelation Evaluated at 5° elevation
Multipath Error	1.0 meter		

*From Reference 9.

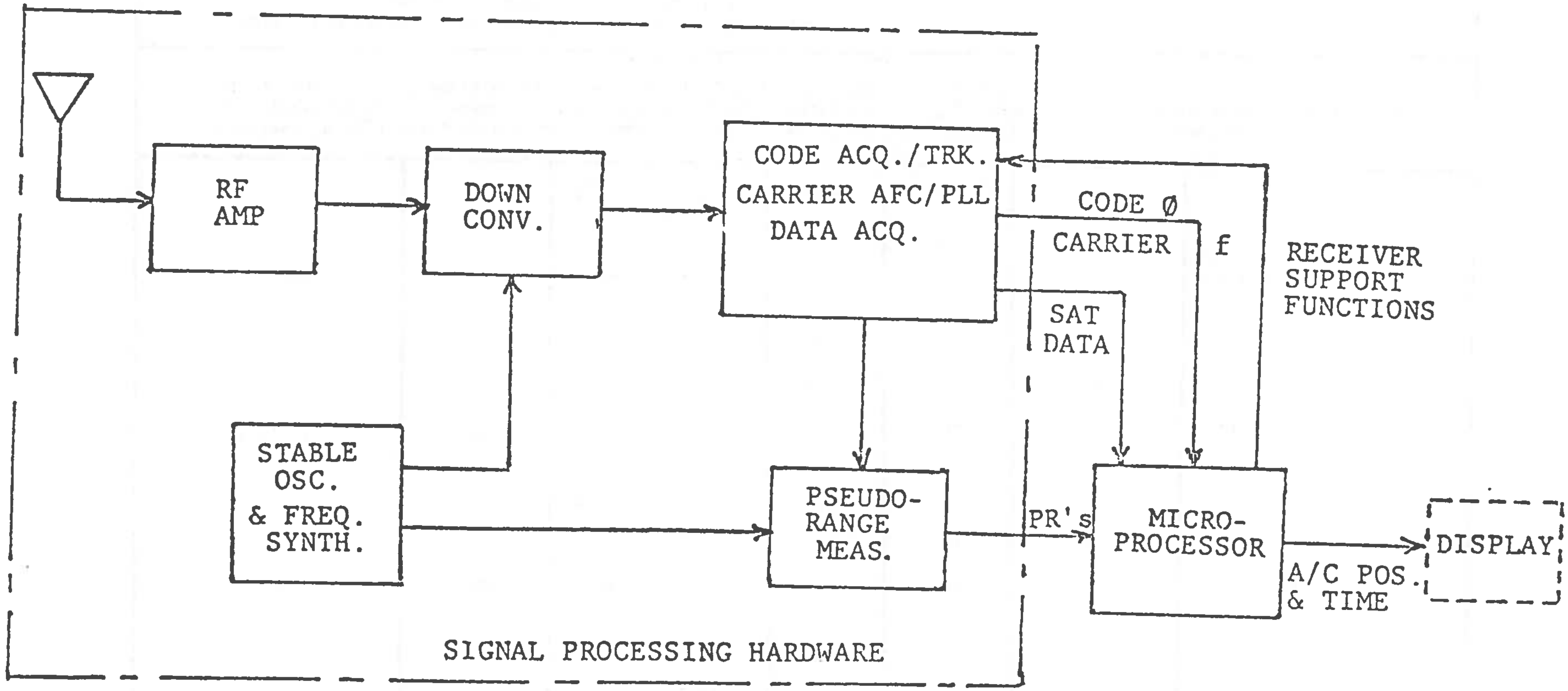

FIGURE 2 OVERALL RECEIVER BLOCK DIAGRAM

might consider integrating coherently only over one epoch (1 msec) and integrate incoherently over four eopchs or 4 msec.

If the code synchronization would test for every code phase in one-half chip steps, and each sync test requires 4 msec, then a brute-force search would require 2046 x 4 = 8200 msec.

However, code-synchronization may require several such searches for different carrier frequency offsets. Suppose only a 3 dB degradation in detection peak is allowable and which was due to carrier frequency error, then the carrier frequency dimension has to be searched in steps of $2\Delta f$ where

$$\Delta f\, T_s = 0.44$$

Assuming coherent detection with T_s = 3.3 msec then

$$\Delta f = 133 \text{ Hz}$$

How many steps are required in the frequency dimension now depends largely on the a priori knowledge of satellite position and availability of user speed and relative user-satellite motion.

<u>Case A</u>: No a priori knowledge

If no a priori knowledge is assumed and user speed is 275 knots, an absolute worst-case doppler is ± 5100 Hz. The synchronization search would require 38 frequency steps or a total of 5.2 minutes. Obviously more complex searching methods such as decision-directed search could reduce that time.

<u>Case B</u>: Almanac data and crude time but no user input.
High elevation satellite.

Assume satellite almanac data are available in memory from which satellite position is reconstructed to within one degree of angular accuracy. Assume user position is available on earth to within one degree of accuracy and the user time agrees with UCT time to within two minutes (or roughly one more degree of satellite angular displacement in earth-centered coordinates). Then the worst-case relative satellite-user angular position error is about 4 degrees or 8 minutes (T_{error}) of time-error. The calculated doppler will be in error with at most

$$T_{error} * \dot{D}$$

where $\dot{D} \cong V_{sat} \frac{f_c}{c} k\, \Omega \cos \Omega\, t$

$$k \varepsilon\, [0.25 - 0.32]$$

$$= 0.25 \text{ at EL of } 5^\circ$$

$$= 0.32 \text{ at EL of } 90^\circ$$

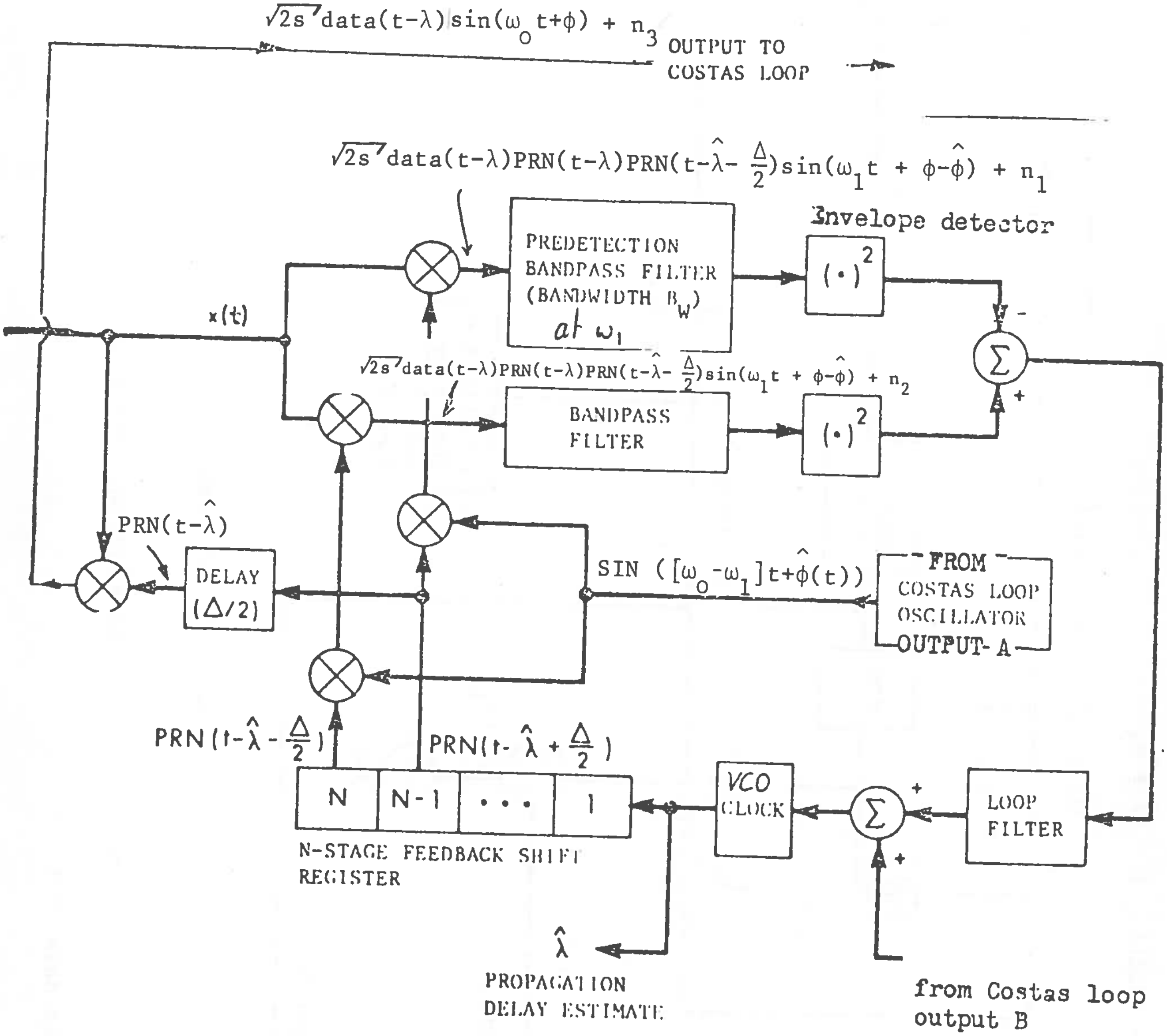

FIGURE 3 DIAGRAM OF A NONCOHERENT DELAY-LOCKED LOOP. THE INPUT (x(t) , IS GIVEN BY:

$$x(t) = \sqrt{2S} \cdot PRN(t-\lambda) \cdot data(t-\lambda) \cdot \sin[\omega_o t + \phi(t)] + n_\phi(t)$$

λ, ϕ are unknown code delay and carrier phase.

steady state situation one would like the loop bandwidth to be very small. This, however, would not allow the loop to react in a dynamic situation. One, therefore, sets up a "cost-function" C to be minimized by choosing 'optimal loop bandwidth' and which contains a weighted sum of dynamic overshoot θ_D and steady-state error σ_ϕ due to persistent higher derivatives or noisy input

$$C = \theta_D + k\,\sigma_\theta \quad k \text{ weighting factor.}$$

To minimize C, a model for the expected dynamics and the filter order must be chosen. Obviously θ_D must always be smaller than the range of linearity π of the error detector.

Once bandwidth B_L is chosen* minimizing C, one can determine the "mininal required C/N_o" to keep the loop output error caused by noise to within a fraction of the linearity region. That ideal was explored in great length in Ref. 6. The expression for σ_θ is also given in the same reference.

AFC Aided Costas Loops

To obtain small steady-state error (or good response to noise only) a small bandwidth is desirable. However, this limits the "pull-in" capability of the loop if the initial frequency uncertainty is large. This pull-in can be effected by a seaparate oscillator with controlling voltage proportional to the frequency error. AFC aiding degrades slightly the performance of the Costas Loop in steady state.

Data Feedback Methods

Several methods exist to feed back data to the input of the Costas Loop to cancel the effect of data-phase transitions. The result also is a better loop performance (Ref. 10, 11).

2.2.3 Code Tracing - Ranging performance is determined by the PN code tracking loop, and corresponds to the chip splitting capability of the loop. Required accuracy will determine whether the code tracking mechanization is done coherently with one correlator only, or incoherently with early/late channel correlators (2 or 4), or if the early/late correlators could be replaced by a time-sequential arrangement using one correlator only.

Performance is expressed by the variance of the measurement error as a function of chip length Δ.

$$\sigma_\Delta = \sqrt{\frac{B_n}{C/N_o}} \left(0.5 + k\,\frac{B_W}{C/N_o}\right)^{1/2}$$

*Hz for 1G dynamics and second order filter loop seems average.

4. AN EXAMPLE OF A PULSED PN CODED WAVEFORM*

4.1 Introduction

In this example, we describe the design of a GPS system based on a pulsed PN coded waveform as opposed to the continuous waveform presently proposed for GPS.

The general intent is to see if great simplifications (and cost savings) can be made in the receiver design and in the navigation processing methods, while meeting all accuracy and operational specifications for GPS.

Section 4.2 presents the GPS requirements and specifications and the assumptions of power and weight allowances for an alternate waveform package on the GPS satellites.

Section 4.3 describes the pulsed TDMA system. In it, the satellites transmit part of their message using short bursts of high energy pulses. The message portion is preceded by a set of identical pulses from which ranging information is derived. The L-band carrier is spread by a PN code (BPSK modulation) at a 4 MHz chipping rate. The data is PP modulated on the spread carrier. The message content would be the same as for the presently proposed GPS system. The analysis resulting in the choice of 16-ary PN modulation is included in 4.3.5.

The motivation to consider a pulsed TDMA system as a first alternative to the present GPS C/A lies in the fact that:

a) The civil aviation receiver will probably be sequential and the logical method for transmission is therefore not simultaneous and continuous but sequential as in the TDMA setup.

b) Signal (re)acquisition must be fast in a sequential receiver. This is done easier with a high power pulsed system than a low power continuous signal.

c) The TDMA approach is better suited for data collection. In the present C/A GPS, a message is transmitted in 30 seconds. Analysis indicates that in a sequential receiver setup, the receiver can stay on one particular satellite only a short time (order of one second). The total message would then be received in fragments.** While in turn listening to four satellites several fragments of the continuously transmitted message will have passed. It will take several times 30 seconds to successfully assemble a message. No

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*This is taken from Reference 17.

**This reasoning does not apply to initial acquisition, where one stays on each satellite long enough to acquire the total message.

distinguished by some orthogonality properties (such as coding) represented an amount of loss of data, and should be avoided.

4.3.1 Power Level - The first consideration is the needed power level. Assuming one wants enough energy to detect with a given probability of detection and false alarm and for a given allowable frequency offset (fixing integration time) the carrier to noise power density at the receiver is more or less fixed.

The frequency offset derives from relative user-satellite motion with maximum value

$\pm$ (4342 + 2.7V) Hz, V user velocity in knots

and the clock offset. Considering V = 375 knots and a clock of a quality 10^{-7} Hz/Hz adds to a total frequency spread of $\pm$ 5500 Hz.

For coherent integration and a 4 dB power falloff, the maximum integration time is roughly 90 µsec. For T_I = 64 µsec, which will be our choise of pulse length, for other reasons, the power fall off is less than 2 dB. For

P_D = 97%, $P_{FA} = 10^{-6}$ the required $\frac{E_o}{N_o} \geq 14$ dB + or $\frac{C}{N_o} \geq 56$ dBHz

since T_I = -42 dBsec. Taking a receiver noise figure of 5 dB or noise power density of -199 dBw/Hz or -199 dB joule the required received power is -143 dBw.

Assuming a receiver antenna gain of 0 dB and a satellite antenna gain of 11.5 dB (to cover the earth completely at the distance 26567 km from earth center*), a path loss of -184.5 dB at frequency L_1 = 1575.4 MHz and the largest distance to the user which is 25824 km at elevation of 5° in user-earth surface coordinates, the required transmitted peak power is more than 30 dBw or 1 kw. Table 4 summarizes the power budget. We have allowed for 1 dB in atmospheric absorption and taken another 2 dB power margin. Transmitted peak power is therefore 2 kw.

4.3.2 Signal Format - We chose a strict TDMA format, allowing only the two satellites in antipodal positions to transmit simultaneously. The total timeframe, of as yet unspecified length, will therefore be divided into 12 slots. Since a time measurement will be obtained from at least four satellites per frame, transmitting in designated slots, the position update rate is determined by the frame length. Update rates should be higher than once per several seconds for adequate tracking performance. An argument can be made that higher update rates not only allow good tracking through maneuvers

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* Gain based on θ = 14° parallax equals $\frac{1}{\sin^2\theta/2} \simeq 12.5$ dB.

or allow the tracking filters to be substantially simpler. Most importantly a high update rate or short frame time avoids the possibility of the short-term clock drift accumulating any substantial timing error. Short-term clock drift is very oscillatory and unpredictable and can not be modelled or tracked easily.

In the design we chose a one half second frame length. In a strict TDMA system the timeslot per satellite pair is then 41.6 msec. To avoid overlap between the transmissions of different satellites (closest at zenith and farthest at lowest elevation) a "minimum" guard time of 17 msec is needed. We took 19.134 msec for other reasons. The useful transmission time is divided into preamble and data transmission as shown on Figs. 5 & 6.

The preamble consists of eight pulses, allowing synchronization with the PN code and accurate timing (ranging). The message portion consists of twenty pulses, each pulse conveying four data bits (see Section 4.3.5 on modulation).

4.3.3 Waveform - All pulses are identical, 64 μsec long. The L_1 carrier is BPSK modulated by of a code 256 chips long, at a 4 MHz chipping rate. The higher chipping rate was chosen over the 1 MHz rate for the present C/A GPS signal in order to reduce sensitivity to multipath by a factor of four. For a 4 MHz rate the altitude above which no multipath effects from a flat surface are felt reduces to abour 2,000 ft for a minimum elevation angle of the satellite of 5 degrees.

Since the signals of the 12 satellite pairs are strictly time multiplexed, a common single code can be used.

4.3.4 Ranging and Synchronization

As shown before the preamble consists of 8 pulses. We consider here the issue of detection, synchronization and ranging. Section 4.1 showed the SNR per pulse at the output of the matched filter to be 14 dB with 2 dB margin. This allows a probability of detection (incoherent phase) of P_D = 97% and a probability of false alarm of 10^{-6}.

The 2 dB margin is used against the drop in SNR due to doppler mismatch. As shown in Sec. 4.3.1, for a worst doppler of $\pm$ 5500 Hz the power falloff of the autocorrelation function is 1.8 dB for a 64 μsec integration time.

The range accuracy in terms of chip-splitting capability is

$$\sigma_\tau = \Delta \frac{1}{2\sqrt{E/N_o}} \leq 0.1\Delta$$

The sampling noise, at 8 MHz sampling rate, adds

$$\sigma_s = \Delta \frac{1}{2\sqrt{12}}$$

The basic accuracy per pulse, for Δ = 250 nsec is

$$\tilde{\sigma}_{R_1} = \sqrt{\sigma_\tau^2 + \sigma_s^2} \simeq 44 \text{ nsec}$$

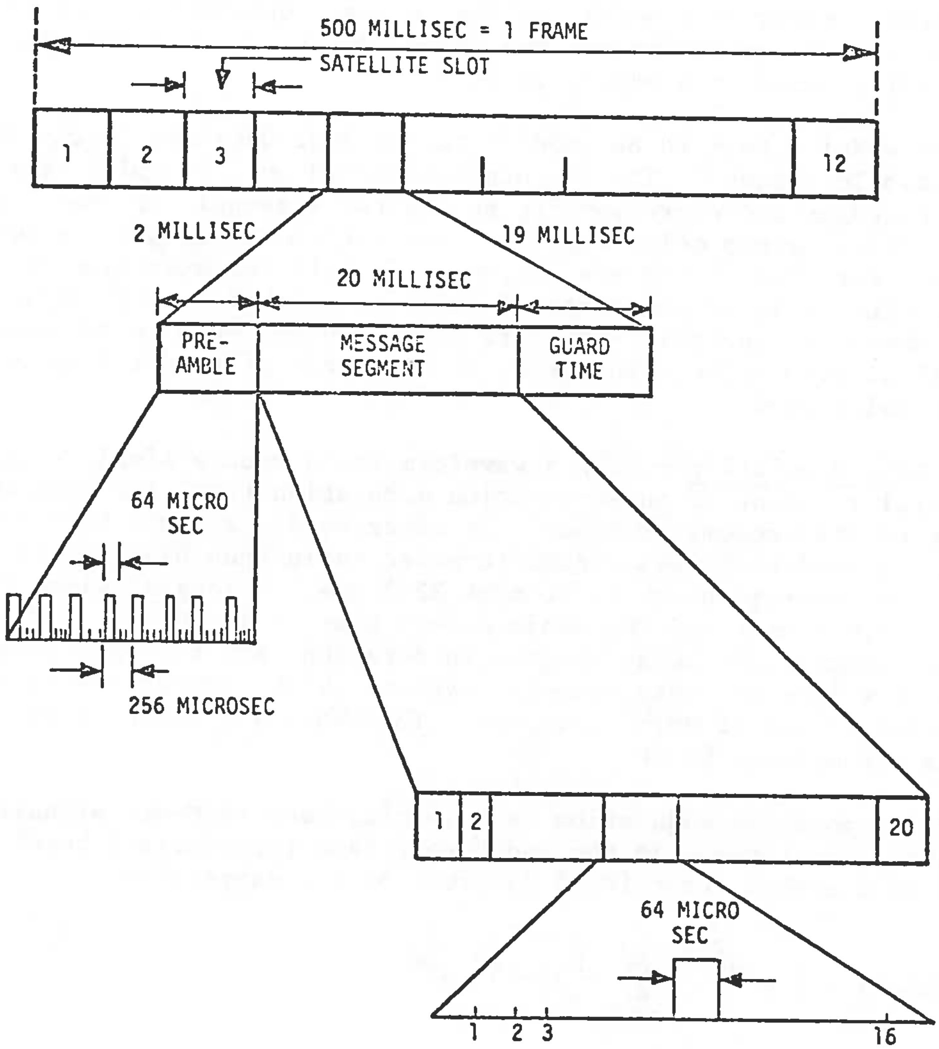

FIGURE 6 PULSED SIGNAL FORMAT

TABLE 5 ERROR BUDGET OF A PULSED GPS WAVEFORM

Basic ranging		
δ_R		15.5 ft
Satellite experiments		5 ft
Multipath (0 above 2,000 ft)		-
Satellite system group delay		3 ft
Atmospheric delay error		5-50 ft
	RSS	17-53 ft

TABLE 6 DATA DEMODULATION

Data message	:1500 bits
Data rate	:80 bits/frame of .5 sec
-	:5 bits for 10/frame
-	message data rate: 75 bits/.5 sec
	or 150 bits/sec

At 14 dB SNR

- Log (probability) of symbol error	: $2.49\ 10^{-5}$
- Average length of error-free run:	: $4.02\ 10^{-4}$ symbols
	= $1.61\ 10^{5}$ bits
	= 107 messages
	= 17.8 minutes

- For independent bit error:

bit error rate : $6.23\ 10^{-5}$

Data error effects can be further reduced, due to redundancy; messages change once per hour.

change-over between constellations is concerned. Even for the parallel GPS receivers, designers, such as TI, are providing 6 instead of 4 parallel channels in order to acquire or track satellites other than those selected for user position determination.

The problem is that when a single satellite becomes undesired (sets below 5° EL for example), it is most often true that no other satellite can replace it to maintain a satisfactory GDOP. Usually a completely new constellation must be acquired and tracked. The short-livedness (order of 10 minutes) of a good constellation makes this a difficult problem for the receiver. The proposed TDMA system would not have such problems.

Acquisition and tracking is virtually instantaneous by design. The signals of all visible satellites are available and can be tracked since they arrive in the strict non-overlapping time-ordered basis at the receiver. All signals have virtually equal strength and are modulated by the same PN code and are on the same frequency. There is no adjusting or reconfiguring necessary on the part of the receiver. The signals can be tracked and the data collected whether or not the processor will use them for user position determination. But it is important that they be available for the background task of selection of the "next" satellite configuration. The switchover from one constellation to the next is unnoticed since all ephemeris data have been collected ahead of time. In the present GPS at least 30 seconds (1 message of 1500 bits) elapse before the ephemerous data are collected for the newly selected satellite and accurate ranging can be done.

The GDOP study also revealed that drastic GDOP changes can occur when changing from one "optimal" selection to the next where it is understood that reselection is only done at regular intervals (every 5 to 10 minutes) or when triggered by such event as one satellite becoming unavailable.

The user position tracker should be designed to cope with such sudden changes in quality of the range "measurements". It should be pointed out that GDOP is a scalar measure expressing linear amplification of the error on a single range measurement, as expressed by the User Equivalent Ranging Error UERE. In reality the geometric delusion is more pronounced in some directions than in others, and these directions and the amplifications suddenly change at the moment of reslection of one or more satellites. The TDMA system has the potential of virtually eliminating that problem. Once the user track is established, the capability exists of incorporating each range measurement separately. There is no limitation to four satellites, but the data from more than four or from all invisible satellites can be used. The idea is based on the fact that such operational mode does not impose an untolerable additional load on the receiver. The processor will process more data but at probably a very moderate increase in cost.

4.5 Comparison of the Sequential C/A Receiver to the Proposed Pulsed Receiver

Figure 8 shows a sketch of a pulsed GPS receiver based on a matched filter (CCD) correlator. We emphasize the absence of DLL and PLL. In addition, the local oscillator can be inexpensive since the pulsed system is insensitive to several kHz of frequency drift. Table 7 presents a comparison of the sequential C/A GPS system and the pulsed TDMA GPS system examined in this

TABLE 7 POWER BUDGET COMPARISON

	GPS CONTINUOUS	GPS PULSED
TRANSMITTED AV POWER	26 w for C/A, L_1	7.2 w
TRANSMITTED PEAK POWER	14.25 dBw	33 dBw
POWER AT RECEIVER ANTENNA	-160 dBw	-141.25 dBw
RECEIVED C/N_o (2 dB CABLE LOSS 5 dB NOISE FIG.)	37.25 dB Hz	56 dB Hz
E_b/N_o AT OUTPUT OF M. FILTER	20.25 dB (over 20 msec)	14 dB (over 64 μsec)

TABLE 8 COMPARISON OF SIGNAL DESIGN FEATURES

ITEMS	SEQUENTIAL C/A GPS	PULSED TDMA GPS
SAT. RADIATED POWER	23 w CONTINUOUS	7.2 w AVERAGE, 2 kw PEAK PULSED
MODULATION	BPSK	BPSK
PN CODE	1023 GOLD CODE	256 CODE
No. of CODES	24	1
CHIPPING RATE	1 MHz	4 MHz
DATA MODULATION	PSK. SUPERIMPOSED ON CODE	16-ary PPM
LENGTH OF DATA BIT	20 msec	4 bits PER 1024 MICROSECONDS
DATA REPITITION PERIOD	(4x) 30 sec	10 sec
MESSAGE LENGTH	1500 bits	[1500 bits INITIALLY]
NOT AFFECTED BY MULTIPATH	ABOVE 8600 ft	2150 ft

TABLE 10 COMPARISON OF OPERATIONAL FEATURES

ITEMS	SEQUENTIAL C/A GPS	PULSED TDMA GPS
CODE ACQ. TIME	80 sec	2.56 msec CODE SYNC. 0.5 sec SAT ID.
TTFF	120 sec	10-20 sec
RANGE UPDATE RATE	0.2 Hz	2 Hz
PSEUDO RANGE ACCURACY (Due to Noise Only)	28 ft	17 ft
NEED FOR RANGE AMBIGUITY RESOLUTION	YES	NO
MEASUREMENT	$R \dot{R}$	R
OUTPUT	3D POSITION 3D VELOCITY TIME	3D POSITION TIME
NAV PROCESSOR OUTPUT	3D POS, VEL, TIME	3D POS, VEL, TIME

REFERENCES

1. Magnavox

   Design Development Study for a Global Positioning System Spartan Set - NRL 85001042 - 4 Sept. 1975.

2. Rockwell

   Global Positioning System Spartan Receiver/Processor SD-75-GP-0006 (11 April 1975).

3. Research Triangle Institute

   Preliminary Study of Navstar/GPS for General Aviation NASA CR-145059 (Nov. 1971).

4. Aerospace Corporation

   Civil Aviation Capabilities of the Global Positioning System FAA-EM-78-1 (Feb. 1978).

5. MITRE Corporation

   Investigation of Satellite-aided ATC System Concepts Employing the Navstar Global Postitioning System DOT-FA70WA-2448.

6. ECM Vulnerability of the GPS User Receiver in a Tactical Environment.

   L. Horowitz, J. Sklar
   Lincoln Lab Project Report XR-1 (May 1976).

7. Spread-Spectrum Applications and State-of-the-Art Equipment

   C. Cahn
   AGARD Series No. 58, paper 5.

8. GPS Briefing - Videotaped Lecture.

   E. Kelly

9. GPS User Equipment Error Models

   E. Martin
   33rd Meeting Institute of Navigation; Cal.

SESSION V
SYSTEM ANALYSIS AND MODELING

Chairman
David Van Meter, Chief
Systems Development Division, TSC

ANALYSIS OF THE PERFORMANCE OF AIDS TO NAVIGATION

Ronald Gress
Office of Marine Environment
and Systems, USCG

ANALYSIS OF THE PERFORMANCE OF AIDS TO NAVIGATION: MODELLING THE PROCESS OF MARITIME NAVIGATION

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ABSTRACT. A two-year project is underway to model the relationship between measurable, physical properties of aids to navigation and the accuracy of navigation. The methodology to be used is a Monte Carlo simulation of the closed loop control system consisting of the mariner, the ship, the environment and the aids to navigation. In addition to serving as a tool to evaluate aids to navigation, the model will also permit the evaluation of safe ship and environmental characteristics for specific ports.

INTRODUCTION

The effort to develop a model to analyze the performance of aids to navigation was initiated by the Coast Guard Aids to Navigation Division of the Office of Marine Environment and Systems. The primary objective of this project is to develop quantitative relationships between the measurable, physical properties of aids to navigation and the accuracy of navigation - the ability of the pilot to direct the movement of a vessel along the desired track.

The Coast Guard's approach to this task involves a two-phase contractual effort. The first phase, just completed, consisted of a three-way design competition over a six-month period. The winner of the competition will complete his methodology over the next two years.

Ultimately, the model is to be completely general, permitting it to be applied to the navigation of any vessel through any waterway using any method(s) of navigation. Initially, however, the model shall address the piloting of large merchant ships in harbor channels and entrances. This scenario was selected because this navigation problem is the most difficult and the probability of an accident is the highest. Also, this is a scenario in which analytical calculations can produce only grossly oversimplified approximations because of the complexities introduced by the dynamic interactions between the ship, its environment and the pilot. The following is a "broad brush" description of the overall approach.

MODEL OVERVIEW

Because of the dynamic interactions, the methodology being developed

The general methodology which best accounts for these and other aspects of the problem is a Monte Carlo simulation which functions like a closed loop control system. A simplified diagram of such a system is shown in Figure 2. Basically, the model is similar to real time, man-in-the-loop ship simulators such as the Maritime Administration's Computer Aided Operations Research Facility (CAORF), except the human element is also being modeled. The model will, however, operate in fast time, thus reducing computer time requirements.

MAJOR ELEMENTS

In developing the model, the contractor will spend most of the next two years investigating and modeling the major elements discussed below. During this period, some factors may be found to be of little importance while others, not now known, may be identified as having a significant impact.

Available Information

The mariner may use fixed marks on shore which provide reference points for fixing position by measuring bearing and/or ranges. Fixed or floating marks may also identify the location of obstructions or other hazards. Fixed or floating marks may also be placed along the sides of the channel, at turn points and channel junctions to mark the limits of safe water and to provide the pilot a visual perspective of the channel, his position in it and the path he should follow. In this latter example, the mariner rarely takes bearings or ranges to the marks to plot lines of position on a chart. Rather, he observes the patterns of aids and visually estimates his location relative to the channel. The identification of a general set of observables used in this process and the quantitative relationships between these observables and the accuracy with which the pilot can estimate his position and the correct path to follow are essential to the model's operation and must be determined largely by experimentation over the next two years.

Other potential sources of information include compass, rate-of-turn indicators, radar and other radio navigation aids. The degree to which these devices contribute to accurate navigation depends to a great extent on the type of information provided, the inherent accuracy of each system, and to some degree, on the display characteristics and format.

Obviously, the visibility is an important factor in that it may limit the detectability and identification of the aids. Factors which influence the ability to detect and identify the aids include the environmental conditions (clear, fog), the time (day, night), the characteristics of the aids (size, color, lighted, radar reflectivity) and the characteristics of the background (contrast and clutter-visual or radar).

The model will determine, based on the actual position of the ship and visibility conditions, what observables are available and used. Then using the appropriate accuracy distributions, it will randomly select a specific set of simulated observable values for each observation.

Information Used

Merely identifying the information available is not enough as the availability of the information does not insure that it will be used by the mariner. Obviously the mariner has preferences which are based on his conception (and experience) as to what type of information or observable is most accurate or reliable. For example, a mariner may tend to rely more heavily on a fixed aid to navigation than a floating buoy because there is a possibility the buoy may have drifted out of position. In another case, certain aids may actually supply more accurate information but may not have gained the confidence of the mariner. Therefore, certain redundant information may be ignored if, from the mariner's point of view, more favorable information exists. The problem becomes one of determining how information from several sources, some perhaps slightly inconsistent with the others, is combined or weighted to produce an estimated location relative to the channel system.

The model will treat this problem by developing a series of probability contours about each of the simulated observations made. Certain observations may be weighted to reflect relative mariner confidence. By statistically overlaying the contours developed for each of the observations, a final series of contours is developed which represents the mariner's confidence that he is at a given location. Generally the mariner will respond (See Control Actions below) based on the maximum likelihood location - the location with the greatest probability or confidence. However, the ability exists to incorporate a risk measure (e.g., a high risk for a location near a channel edge or hazard). The mariner would then respond to reduce his risk by basing his actions as if he were located at that position which has the greatest risk/likelihood combination.

Control Actions

The mariner makes his control decisions based on his perceived location (i.e., cross track and along track location) and on his estimated direction of travel relative to his desired track in the channel segment. The direction of travel may be estimated directly or by comparing past to present position. The desired track along the channel is perceived not as a line but as a band or zone of indifference. As long as the mariner feels he is within this band, he is comfortable and attempts no course correction. Outside of this indifference band there may be several other bands (Figure 3) which may represent increasing degrees of control strategies. This approximates the non-linear control aspects exhibited by the human pilot. Turn strategies are primarily influenced by the pilot's ability to estimate his distance to the turn, the sharpness of the turn and channel width, and his knowledge of the ship's behavior characteristics. Once the turn is initiated, the mariner may correct his ship's trajectory based on his perceived location and projected motion versus his planned path as in the simple course correction algorithm. Traffic avoidance maneuvers will also be incorporated.

While the model will contain a generalized set of decision and action commands, the user will have the capability of developing his own set. In this manner, different mariners (experienced versus inexperienced) and different mariner strategies can be examined.

The model can be used, together with the direct results of research performed in the model development, to establish standard practices in the design of local systems of aids to navigation. Also, working backwards, standards of performance for particular aids to navigation can be identified which are required in order to obtain acceptable levels of risk. For example, as part of the research and model testing, the most effective method(s) for displaying position and guidance information acquired from a precision radio navigation system, and some idea of the accuracy and update rates that may be required to meet certain safety levels will be studied.

The nature of the model lends itself to uses outside of the evaluation of aids to navigation explicitly. Trade-offs between different aids to navigation or navigational aids can be examined. Other alternatives, such as channel enlargement can be considered for their cost effectiveness. Regulatory actions such as speed limits, traffic control (e.g. one-way traffic) or the requirements for tugs can be partially evaluated with the model. Decisions regarding the ability of new or larger ships to safely use a port as configured can be aided and possible limits on adverse environmental conditions established.

While the model may not produce results upon which a direct decision can be reached, it certainly should prove to be a valuable tool to aid such decision making. In a project which will require more costly experiments such as real time simulation or at sea trials, the model can be used to limit the test conditions to those most likely bounding the problem and thus reduce the amount of detailed, costly testing required.

REFERENCES

W. R. Bertsche, "Study of the Performance of Aids to Navigation Systems - Phase I, An Empirical Model Approach," U. S. Department of Transportation, U. S. Coast Guard, July 1978, CG-D-36-78.

W. H. Clark, "Study of the Performance of Aids to Navigation Systems - Phase I, Closed Loop Model of the Process of Navigation," U. S. Department of Transportation, U. S. Coast Guard, March 1978, CG-D-38-78, 511 pp.

E. Lofgren, "Study of the Performance of Aids to Navigation Systems - Phase I, A Control Theory Approach," U. S. Department of Transportation, U. S. Coast Guard, July 1978, CG-D-37-78.

AVIATION-NAVIGATION COST ANALYSIS MODEL

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AVIATION NAVIGATION COST ANALYSIS MODEL

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ABSTRACT This paper summarizes an activity which consisted of:

a. The development of a life cycle costing computer model to assist in the evaluation of overall civil aviation navigation costs.

b. The development of cost data for avionics components and ground elements for the various alternative navigation systems under consideration.

c. Exercising the model to obtain an initial estimate of the cost impact of various scenarios consisting of system combinations over various periods of time in different geographic areas.

Major systems evaluated were VOR/DME, LORAN C, OMEGA, and NAVSTAR/GPS. Continued use of VOR/DME as the prime short-range navigation aid was found to be the least costly alternative. A rapid, forced transition to NAVSTAR/GPS was found to be most costly.

INTRODUCTION

Planning in the navigation area must be based upon an evaluation of a number of factors---technical, operational and economic. At times, political and international considerations also play an important role. This paper will present some details on how the FAA has gone about the initial steps of evaluating the economic impact to the civil aviation community and to the FAA of various alternative navigation systems and scenarios. The paper describes a contractual activity which was initiated approximately two years ago by the Office of Aviation System Plans with Systems Control, Inc., of Palo Alto, California. Its overall objective was to evaluate the costs of implementing alternative navigation systems in various geographic areas such as CONUS, Alaska, Offshore and Oceanic.

The activity described herein is currently limited to the civil aviation user community and to the FAA. It has to date not addressed the broader issues of costs to the Government as a whole, the international aviation community or non-aviation users. The methodology would, however, be suitable for a broader analysis.

Since systems may be unique to various geographic regions, operator (Government costs) are broken down by region. In this way, separate systems, or combination of systems, can be evaluated independently for CONUS, CONUS Offshore, Alaska, Alaska Offshore and Oceanic regions. Where possible, both implementation and recurring costs have been specified by component element (e.g., R&D, staffing, charting, training, overhead, spares).

It should be noted at this point that since the model addresses civil aviation navigation costs, the costs to the Government of operating military or non-aviation navigation systems are not processed by the model. Thus, for systems such as GPS and LORAN C, the model processes only the incremental civil aviation costs. For GPS, as an example, while cost estimates are included for both the civil and military sectors, only the civil costs, which are limited to factors such as charting, headquarters staffing and civil signal monitors, are processed. The costs of operating the ground and satelite segments are assumed to be fully borne by the military and are not included in the processing. Similarly in the case of LORAN C, the FAA is assumed to bear the cost of the additional stations required to bring the system up to sufficient capability to meet aviation requirements. Other LORAN C costs are assumed to be borne by the Coast Guard. The model contains the capability to shift any desired percentage of costs into or out of the civil (FAA) category, so that it can to used to test the impact of potential policy changes in navigation funding.

It was felt that critical aspects of the economic impact would be both the overall cost impact to the users, and also the total impact upon the various user groups. Allowing the analysis to address user groups individually would enable those groups to determine the cost impact of primary interest to them and allow the FAA to evaluate whether policy or technology changes would affect certain groups more than others. A user group matrix was establsihed by type of aircraft (4), sophistication of avionics (10), region of operation (8) and use to which the aircraft was put (4). This matrix of over 1000 elements was then compressed into 98 groups by eliminating and combining elements which were either illogical or had a small number of aircraft in them. Population projections for each of these 98 groups were then obtained by utilizing official FAA forecasts and expanding upon those forecasts to the level of detail needed for the modeling activity.

When the population data for each of the 98 groups in the matrix was completed, provision was made to include user cost data for all elements in the matrix. Costs may be specified separately for items such as avionics purchase, installation, maintenance, and antennas. Costs may also be a function of whether the system is being installed in a new aircraft or being retrofitted into one already having a navigation system.

where C_1 is the cost of the first item and P is the learning curve factor. Based upon subcontractor supplied historical data and discussions with cognizant personnel, P was chosen to be nominally 0.9. Also, based upon the relatively fragmented nature of the avionics industry and the fact that most avionics are manufactured in relatively small production runs, it was decided to allow the production curve to go flat after 20,000 units were produced of each type in each grade. Prices thus obtained for the 20,000th unit, in 1977 dollars, are shown in Table 1. Note that cost assumptions made for VOR are quite conservative.

Table 1
Avionics Costs

NAVIGATION SYSTEM TYPE	AVIONICS COMPONENT DESCRIPTION BY GRADE	ESTIMATED PRICE OF 20,000 AND SUBSEQUENT UNITS (1977 DOLLARS)
VOR	VOR (A)	$ 1,495
	VOR (B)	1,604
	VOR (C)	3,318
	VOR (D)	3,919
	DME (A)	NA
	DME (B)	$ 3,695
	DME (C)	3,947
	DME (D)	9,422
	RNAV (A)	NA
	RNAV (B)	$ 2,015
	RNAV (C)	6,677
	RNAV (D)	6,677
SELF-CONTAINED	INS	$62,160
	OTHER S.C.	16,430
LORAN-C	LORAN-C (A)	$ 2,998
	LORAN-C (B)	3,547
	LORAN-C (C)	5,097
	LORAN-C (D)	11,173
OMEGA	OMEGA (A)	$ 2,998
	OMEGA (B)	3,547
	OMEGA (C)	5,097
	OMEGA (D)	11,173
DIFF. OMEGA	DIFF. OMEGA (A) .	$ 3,748
	DIFF. OMEGA (B) .	4,313
	DIFF. OMEGA (C) .	5,911
	DIFF. OMEGA (D) .	12,173
GPS	GPS (A).	$ 5,765
	GPS (B).	6,719
	GPS (C).	10,242
	GPS (D).	23,201

RESULTS

After having completed model development and collecting a reasonable initial set of data, a number of scenarios were hypothesized. The model was then exercised to evaluate these scenarios and determine cost sensitivities. Over a hundred model runs were made.

The first model runs were oriented toward establishing the cost for a "baseline" (or current) system. The baseline consisted of VOR/DME for use in CONUS and Alaska, and OMEGA for use in all other areas. OMEGA was assumed for Oceanic use because the Air Carriers appeared to be trending in that direction due to the expense of maintaning inertial systems. It was presumed that by 1985, OMEGA would probably be certified for Oceanic use. Note, however, that if it were assumed that Air Carriers used inertial systems, the overall cost impact would not be significant because of their rather limited number.

Another issue that had to be evaluated in establishing a baseline was whether to use an upgraded (solid state) VOR/DME system or a second generation VOR/DME as proposed for implementation by the FAA. The second generation system, which included remote maintenance monitoring aids, was found to be highly cost effective, and it was assumed that the necessary funds would be expended to implement it. Second generation VOR/DME was thus used as part of the baseline.

The costs of the various alternatives in relation to the baseline are presented in Figure 2. That figure depicts cumulative costs to the system users, to the FAA, and to the entire aviation community through the year 2005, based upon a 7% inflation rate. Note that the figure represents cumulative costs, and dollars depicted therein are not discounted to present value. The "nominal" transition in each case is assumed to be one starting in 1990 and allowing for ten years of full overlapping coverage between the baseline and the new system. The four cases addressed are:

a) Continued use of the baseline.

b) LORAN C for all areas except Oceanic; OMEGA used for Oceanic coverage.

c) GPS used in all areas.

d) GPS used in all areas supplemented by continued existence of VOR for low cost users.

Before elaborating upon the results, some of the key assumptions and dependencies should be highlighted:

a) Only direct cost issues are addressed. All systems are assumed to meet minimum requirements. Benefits obtainable from potentially exceeding requirements are not considered. Conversely, secondary costs associated with items such as developing new air traffic control procedures, retraining controllers or reconfiguring FAA communications services to continue broadcasts currently utilizing VOR transmitters are not addressed.

b) The FAA is assumed to incur only the incremental costs associated with operation for civil aviation. Thus, NAVSTAR/GPS which would already be suitable for civil aviation is essentially a no-cost system to the FAA. Full costs estimated for the second generation VORTAC program are included.

c) Key cost parameters are \$1495 for a low cost VOR receiver; \$2998 for a LORAN C and \$5765 for GPS. These prices represent an attempt to pick a "typical" low cost unit rather than the lowest cost one available. Costs are in 1977 dollars and assume volume production.

A number of things are apparent from looking at Figure 2. Firstly, user costs far outweigh Government costs. Secondly, the timing of the start and duration of any transition period can have significant impact upon both the Government costs and the user costs. Based upon the input data used, continued use of the baseline appears to be the most economically attractive solution. Civil transition to GPS appears to be the most costly solution. The high cost of the GPS scenarios stems from the fact that user costs were far higher than for any other of the scenarios. This was primarily due to the price associated with the low cost receiver. Detailed evaluation of the costs to the various user groups indicated that the groups primarily impacted by the transition to GPS would be the low cost General Aviation users; essentially those currently equipped with a single VOR or dual VOR and no DME or other more sophisticated equipment. Because of this cost burden, a number of scenarios were run where GPS was presumed to be operational for civil use, but the full VOR system was operated in parallel with it. This allowed the low cost users to retain their VOR equipment and precluded their need to transition to GPS. In running these combination GPS/VOR scenarios, the very conservative assumption was made that the entire costs of VOR/DME were still incurred by the FAA even though DME equipment at this point was not being used by any aircraft in the fleet. Even with this conservative assumption, however, the savings accrued by the users far outweighed the additional Government costs. This indicated that unless an effective low cost receiver could be developed for GPS, the civil community appeared to be better served by allowing VOR to operate in parallel with GPS.

The major conclusion from the above is that there do not appear to be any cost advantages to a forced rapid transition to an alternative navigation system. The key to the economic viability of any navigation system is the development of a technically and operationally suitable receiver for the low cost user. It would thus appear that the civil community would be better served (economically) by allowing for a gradual transition after providing adequate time to thoroughly assess all technical and operational considerations and their price impact.

The model runs, the analysis and the subsequent report emphasized GPS and VOR/DME fairly heavily as these appeared to be the major systems facing the navigation community at the time. However, it should be stressed that the model can be used to evaluate the cost of any aviation navigation system that is currently in existence and can also adapt fairly readily to future systems. All that is needed to evaluate a system are a set of avionics cost parameters and a set of costs for Government operated equipment.

The Government now has a tool available within its inventory to evaluate the impact of navigation equipment cost changes; to determine the cost impact of transferences between the civil and military sectors; to allow users to judge the individual impact upon their operation; to determine whether unique systems in particular geographic areas may be better suited than global or national systems, and to evaluate the impact of avionics cost changes and the costs of various implementation and transition strategies.

Current plans call for reassessment of costs as better data is developed. Enhancement of the model capabilities and increasing its sophistication are also planned. A supplement will eventually be issued to the present report.

Model development and the subsequent analytic activities are documented in Report No. FAA ASP-78-3, entitled "Economic Requirements Analysis of Civil Air Navigation Alternatives." This report is available from the FAA, Office of Aviation System Plans (ASP-120).

CONCLUDING REMARKS

James Andersen, Director
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CONCLUDING REMARKS

James Andersen, Director
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Now that we are closing the first "Conference on Navigation in Transportation" I would like to recap the major highlights of the conference and try to put a little perspective on what you have heard.

Jack Fearnsides opened the conference with a statement of the "Issues Facing the Department in Navigation." One issue is clear and quite important. This issue deals with the responsibility for planning and managing civil navigation systems. Past shortcomings and lack of high level attention to these issues within the Department have led to pressures from outside DOT to either "get our act together" or, perhaps, lose some of our authority in the field of navigation. I think from the speakers in our first conference session you can see that we are, indeed, "getting our act together."

I think you have a good understanding of some of the key decisions on navigation systems that will have to be made in the next five years. These range from the role of the DOD NAVSTAR/GPS system in civil navigation to the proper DOT role in providing a land navigation capability, the requirements for which are not fully developed.

From the technical papers I hope you got a good appreciation of the breadth and scope of activities within DOT. I would like to add a little perspective to what you heard because I feel many of you might leave this conference thinking 95% of the efforts of the DEPARTMENT deal with LORAN-C. Most of the papers presented did indeed deal with LORAN-C applications. I think this is natural because at this point in time, LORAN-C R&D is, indeed, where there is a lot of activity. For air navigation, VOR/DME is a very mature system and very little R&D is being conducted. In the very near future GPS R&D will be a very significant effort within the DEPARTMENT and you will undoubtedly be hearing a great deal about it. In marine navigation, LORAN-C properly deserves a great deal of attention because of the increasing importance of navigation to safety of our maritime operations. In land navigation, LORAN-C is basically the only potentially useful wide area navigation system for the immediate future.

I think the current interest in LORAN-C is due in part from the desire within the DEPARTMENT to make best use of what we have before we "create" the requirement for a new system to meet our navigation requirements.

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